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ELEMENTARY SCIENCE MANUALS.

MAGNETISM & ELECTRICITY

FOR

Schools and Science Classes.

BY

GEORGE PORTER,

HEAD MASTER, COLERAINE MODEL SCHOOL; AUTHOR OF
"ALGEBRA FOR SCHOOLS."

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PREFACE.

This manual, as its name implies, is intended as a text-book for Schools and Science Classes. While not a mere expansion of any particular syllabus, it will be found to cover the course of study prescribed by the Commissioners of National Education, as well as the Elementary Course of the Department of Science and Art, South Kensington.

The arrangement of subjects here adopted differs somewhat from that which usually obtains: it is the order which the Author has found best adapted for beginners, and best calculated to obviate the employment of technical terms not previously explained.

The questions (omitting duplicates) that have been proposed at the Government Science Examinations (Elementary Stage) during the years 1867–76 inclusive, are here given, arranged to suit the text. Advanced questions are marked with an asterisk (*).

Following each question is the number of the Article to be consulted in answering it, while in the text itself frequent reference is made to other Articles treating of corresponding facts or explanations. These will materially assist the student in *digesting* the subjects dealt with, but he has no more right to expect each question to be *directly* answered, than to expect a work on Arithmetic to contain the solution of all the exercises it contains.

Model School, Coleraine,
March, 1878.

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MAGNETISM AND ELECTRICITY.

CHAPTER I.

MAGNETS.

1. **Magnetism** is the science which treats of the nature and properties of magnets. The term is often employed to designate the power which magnets possess of attracting iron. Though iron is most easily affected by the magnet, there is, perhaps, no substance wholly indifferent to its power.

Magnets are either *natural* or *artificial*. The natural magnet, or loadstone, consists of an ore of iron of a greyish or reddish-black colour. The Greeks called it *magnes*, or the magnesian stone, because they obtained it from Magnesia, a town in Asia Minor. From these names are derived the terms, *magnet*, *magnetism*, &c. This ore is found in all quarters of the globe, but does not always possess magnetic properties.

Artificial magnets are simply magnetised bars of well-tempered steel. If these bars are straight and of the same thickness throughout, they are called *bar-magnets;* if bent of a horse-shoe shape, they are called *horse-shoe magnets*. *Magnetic needles* are small straight magnets whose ends taper to points.

As artificial magnets possess the same properties, are more powerful and more conveniently used than natural ones, they alone will be referred to as "magnets."

2. **Polarity.** If we roll a magnet or a piece of loadstone in iron filings, they will adhere to it, arranging themselves in feathery tufts around its ends, and diminishing in quantity towards the middle of the magnet, which will be left bare. The ends of the magnet, where the attraction is greatest, are called its *poles;* the middle of the magnet, where there is no apparent magnetic force, is called the *neutral line, or magnetic equator*. It is thus shown that the magnetic force gradually diminishes in intensity from the poles to the neutral line. The *following* pretty experiment also shows the distribution of

the magnetic force:—Lay a plate of glass or a sheet of stiff drawing paper on a magnet, and strew fine iron filings over the glass or paper. On tapping the table on which the magnet rests the filings will arrange themselves in certain lines (Fig. 1), which indicate not only the position of the magnet, but the directions in which its force travels. These lines are called *magnetic curves*, or *lines of magnetic force.* The preceding experiments prove that both poles agree in attracting soft iron (Art. 4). But they disagree in some important particulars. Thus, suppose a bar magnet is freely suspended (Fig. 2), say by means of a stirrup of some non-magnetic substance, or a strip of paper passing round its middle (Fig. 10) and hanging from a fine thread, it will come to rest with one of its poles pointing north (the other, of course, pointing south), and if moved from this direction it will, after a number of oscillations, return to it again, each pole when at rest always pointing its own way. The pole which points north is called the north, or north-seeking, pole of the magnet—the other the south, or south-seeking pole. Thus to each pole of the earth the needle presents two ends, which *are differently endowed.* "Two opposite kinds of magnetism

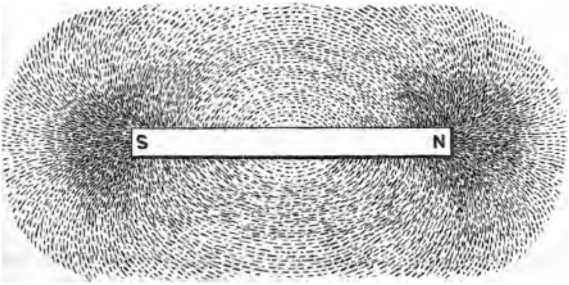

Fig. 1.—MAGNETIC CURVES.

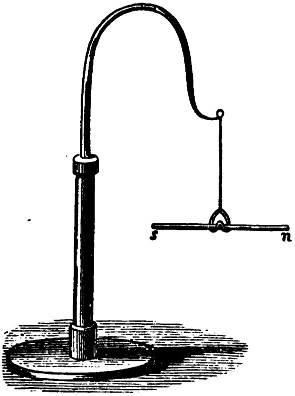

Fig. 2.—FREELY SUSPENDED BAR MAGNET.

may be supposed to be concentrated at the two ends. In this *doubleness* of the magnetic force consists what is called *magnetic polarity.*—Tyndall, Notes, *Elect. Phen.*, p. 6. The poles of a magnet are either marked with the letters N and S, or a file-cut is made in the north end.

3. **Like poles repel each other; unlike poles attract each other.** Suppose the north pole of a bar magnet held in the hand is presented to the north pole of a magnet freely suspended (as in Fig. 2), the free magnet will turn its north pole away from the north pole of the other. If the magnets be sufficiently near each other, the south pole of the free magnet will move towards, and perhaps touch the north end of the stationary magnet. In like manner, if we had presented the south pole of our stationary magnet to the south of the suspended one, the latter pole would have been driven away, and its corresponding north pole drawn to the presented magnet. From this experiment is deduced the *law of magnetic* attractions and repulsions—viz., *like poles repel; unlike attract.*

4. **Magnetic substances.** Suppose that in the last experiment instead of a magnet we had held a bar of iron in the hand, it would have attracted *either* end of the magnet to which it had been presented. Substances which attract or are attracted by both ends of a magnet are called *magnetic substances* (Art. 2). They do not possess polarity, and exhibit no mutual attractions or repulsions. Besides iron, nickel, cobalt, chromium, and manganese are magnetic substances (Art. 1); but iron alone, or rather steel (Art. 11), can be permanently magnetised.

5. **Magnetoscopes** are instruments for determining whether a body is magnetic or not. A simple kind of magnetoscope consists of a small magnetic needle delicately balanced on a fine needle of steel (Fig. 3), or suspended by a silk fibre (Fig. 2). If both poles of the needle are attracted by the same end of the substance to be tested, it is *not* a magnet; but if one pole is attracted and the other repelled by the same end of the substance, it *is* a magnet. The law of magnetic attractions and repulsions enables us in the latter case to distinguish the north and south poles of the magnet, knowing those of the needle.

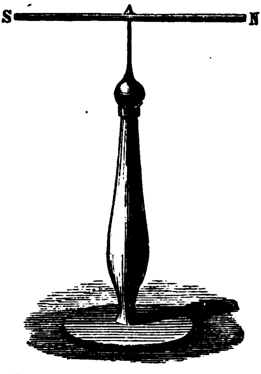

Fig. 3.—MAGNETOSCOPE.

6. Theory of magnetism. Hypothesis of two magnetic fluids. In order to explain the various phenomena of magnetism, it is assumed that each molecule* of a magnetic substance, as well as of a magnet, is itself a magnet, *because* it is surrounded by equal quantities of two magnetic fluids, called respectively the north magnetic fluid and the south magnetic fluid. These fluids are each self-repulsive, but both mutually attractive; that is, the north fluid repels north and attracts south, while the south fluid repels south and attracts north. In a magnetic substance the fluids are combined round each molecule so as to neutralise each other, whereas in a magnet the fluids are separated from each other—but not from their common molecule—the north fluid of each molecule pointing towards the north pole of the magnet, and the south fluid of each molecule pointing to the south pole of the magnet. It must be borne in mind that the attractions and repulsions apply to the fluids only, and not to the molecules which they surround.

This theory is not to be looked on as a proved scientific fact, but merely as an image which affords a convenient means of connecting and classifying facts. Indeed there is no reason whatever for believing in the existence of such fluids.

7. That this important theory may be clearly understood, and its utility exemplified in the explanation of magnetic phenomena, we shall endeavour by its means to present a clear image of the state of two mutually-attracting bar magnets. Suppose N S (Fig. 4) to represent a bar magnet, and N S a small magnetic needle—so small as to consist of a single molecule. The alternate shaded and blank spaces may be supposed to represent the positions of the north and south fluids respectively, as arranged round the molecules of which the magnets consist. All the shaded spaces containing the north fluid point towards one end of each magnet—the north pole; all the blank spaces containing the south fluid point towards the other end—the south pole. Such being the disposition of the fluids, it may naturally be asked *why the needle should move towards the magnet.* In order to understand this tendency, let

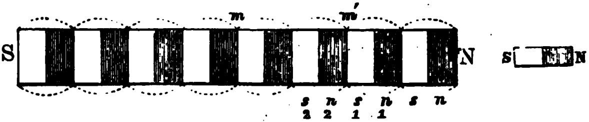

Fig. 4.—BAR MAGNETS ATTRACTING EACH OTHER.

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* The smallest particles into which a body can be divided are called its *molecules.*

us fix our attention first on the action of the needle and the molecule *n s* nearest it. The south fluid S of the needle attracts and is attracted by the north fluid *n* of the molecule, but repels and is repelled by the south fluid *s* of the molecule. But the attracting fluids S *n* being nearer each other than the repelling fluids S *s*, the attraction is greater than the repulsion; hence, as far as the molecule *n s* and the south fluid S of the needle are concerned, there results a tendency to draw the needle towards the magnet. Just in the same way the mutual attraction of *n* and S exceeds the mutual repulsion of s_1 and S, the mutual attraction of n_2 and S exceeds the mutual repulsion of s_2 and S, &c., &c., &c.

But the attractive power of the north pole N of the magnet is the sum of the attractive powers of n, n_1, n_2, &c.; and the repelling power of the south pole S of the magnet is the sum of the repelling powers of s, s_1, s_2, &c. Hence, as far as the magnet and the south fluid of the needle are concerned, we have a resultant attractive force. And, being nearer, the south fluid of the needle attracts the magnet more strongly than its north repels it. We thus see that the *mutual* attractions are greater than the mutual repulsions, and that simply because the attracting fluids are nearer each other than the repelling. Similar reasoning explains the repulsion of like poles. In all cases of magnetic attraction or repulsion both forces are at work, the resultant attraction or repulsion being their difference.

From the foregoing explanation it will be seen that the magnetic fluids, and, consequently, the *magnetic force, is distributed throughout the mass of the magnet.* The *free* magnetism is most powerful at the ends simply because all the north fluids point towards and tend to act through one end—called the north pole, and all the south fluids point towards and tend to act through the other end—the south pole. As there is an equal amount of north and south fluid on each side of the middle of the magnet, there is no free magnetic force at the neutral line.

8. Experiment with broken magnets. That the magnetic force, though apparently concentrated at the ends, is really distributed throughout the mass of the magnet, may readily be proved by breaking the magnet in the middle, when each half will be found to be a perfect magnet, having two poles and a neutral line. If we again break these halves, each broken part is still a magnet, and so on as far as we carry the division. From this experiment we infer that each molecule of the magnet is itself a magnet; the action of the magnet as a whole being the sum of the actions of its molecules.

The poles at the line of fracture are of the opposite names to those of the original ends of which each formed a part. Thus on breaking the magnet N S (Fig 4) at *m*, N is still the north pole of its own half, the other end of this half being south. If we now break this half at m^1, N is still north and the end at m^1 south, &c., &c.

The polarity of each broken part can be readily tested by the magnetoscope, and the experiment conveniently made with a magnetised knitting needle.

9. **Magnetic induction.** When the extremity of a bar of soft iron *a* is placed in contact with either pole of a magnet, as in Fig. 5, the bar itself immediately becomes magnetic, the pole in contact with the magnet being of the contrary name to the pole of the magnet which it touches. The disposition of the poles is denoted by the letters *n s*. The magnet S N is called the *inducing* magnet, and the *induced* magnet *a* is said to be magnetised by *induction* or *influence*, which is defined as "the action in virtue of which a magnet can develope magnetism in iron.—Ganot's *Physics*, p. 562. If the inducing magnet is sufficiently strong, a second bar of soft iron (*b*) may be suspended from the first, a third from the second, and so on, while nails or iron filings will adhere to the last. On removing *a* from the influence of the inducing magnet, the bars which were suspended from it immediately fall, and retain no trace of magnetism. The magnet parted with none of its power to the bars; it simply separated their fluids, which recombine on being removed from its influence. Hence we cannot liberate the north fluid without liberating in the same body at the same time an exactly equal amount of south, for, as we have seen, these fluids when recombined neutralise each other.

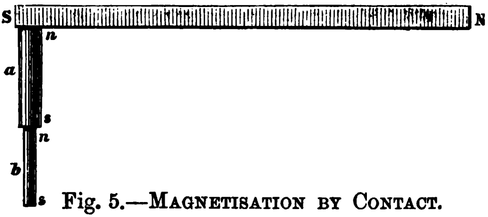

Fig. 5.—MAGNETISATION BY CONTACT.

In order to magnetise a piece of soft iron by induction, it is not necessary that it should be in actual contact with a magnet. When a bar of soft iron B is presented to one of *the poles of a magnet* A, as in Fig. 6, the bar becomes magnetic, and may possess sufficient power to induce magnetism in the bar C, &c., &c. The inductive force exerted by each magnet on the other will increase as they are brought nearer, till, when A, B, C, &c., touch each other as they lie, the three are converted into one long magnet, whose north pole is *n* (of C), and south pole *s* (of A). That B, C, &c., are magnetic may be shown by strewing iron filings over them. The separation of A, B, C, &c., from each other by any non-magnetic substance, such as glass or wood, will not affect their mutual action.

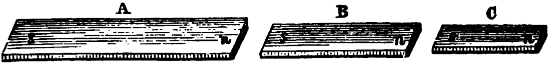

Fig. 6.—Magnetisation by Induction.

The two-fluid theory thus explains the foregoing experiment. The magnet A acting on the soft iron bar B by induction decomposes its magnetic fluids, attracting its south—because the north end of the magnet is presented to the bar—and repelling its north. The bar B being now converted into a magnet acts on the bar C by induction, decomposing its fluids just in the same way as A acted on B, &c., &c. As the attracting ends of the magnets are nearer each other than the repelling ends, the induced and inducing magnets have always a tendency to come together. It is thus evident that, on presenting a piece of iron to a magnet, the iron, before attracting or being attracted by the magnet, becomes itself a magnet, so that, strictly speaking, *magnetic attractions and repulsions take place between magnets only.*

Induction accounts for the adhesion of iron filings to the poles of a magnet, and for the peculiar arrangement of the filings exhibited in Fig. 1. The layer of filings next the magnet become induced magnets, which act on the next layer, and so on, each filing setting itself lengthwise in the same way as the small bars of iron.—Fig. 5.

10. Armatures, or keepers. Magnets soon lose their power when roughly handled or allowed to fall frequently, and even when at rest there is a constant loss if they are not protected from the influence of the earth's magnetism (Art. 13). For this reason the opposite poles of magnets, when not in use, are joined by a piece of soft iron called an *armature*, or *keeper*. One keeper is sufficient for a horse-shoe magnet. Bar magnets are generally kept in pairs, lying parallel, but not in contact, with their opposite poles pointing in the same direction, and joined by keepers.

The action of the armature is easily understood. The south pole S of the horse-shoe magnet (Fig. 7) acts by induction on the soft iron armature, attracting its north fluid towards *n*, and repelling its south towards *s*.

This decomposition of the fluids of the armature is assisted by the north pole of the magnet attracting the south fluid of the armature and repelling its north. Thus each pole of the magnet assists the other in rendering the armature powerfully magnetic. And the armature now reacts on the magnet so as to effectually shield it from the much weaker force of the earth, while the mutual attractions of magnet and armature are sufficiently strong to support a weight suspended from the armature much heavier than the magnet alone could support.

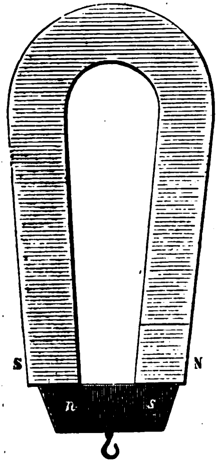

Fig. 7.—Horse-shoe Magnet & Armature.

11. Coercive force. The force with which the opposite fluids are combined varies in different bodies. In some the fluids require but little power to overcome their mutual attraction—that is, to magnetise the body; in others, considerable force is requisite. The fluids when separated have always a tendency to recombine, and the facility with which this recombination takes place is proportionate to the ease with which they were separated. Soft iron offers a very feeble resistance to the decomposition of its magnetic fluids, and an equally feeble resistance to their recomposition. It is easily magnetised, and as easily demagnetised; in fact, it cannot be made to retain its magnetism for any length of time. Steel, on the other hand, is more difficult to magnetise, and retains its magnetism for a long time—hence artificial magnets are made of steel. This property, which it possesses in proportion to its hardness, is called *coercive force*, which may be defined as the *resistance offered by a body to magnetisation* or to *demagnetisation.*

12. Magnetisation by friction. Three methods of producing artificial magnets by friction are commonly practised.

Single touch. Place the bar to be magnetised on a table, and rub it from ten to twenty times in the direction of its length with one of the poles of a powerful bar-magnet. *Or*, rub the *bar from its middle to* one end a number of times with one pole of a magnet, and then rub it an equal number of times from the middle to the other end with the other pole. In the several kinds of "touch" one rule determines the disposition of the poles in the magnetised bar—viz., the north pole of the bar will be that end last touched by the south pole of the magnet. Of course the opposite end of the bar will be south.

Divided touch. This method will be best understood from Fig. 8, where *n s*, the bar to be magnetised, is placed on a piece of wood with its ends resting on the opposite poles of two permanent magnets. Two rubbing magnets, inclined to the bar at an angle of about 30°, have their opposite poles placed on it all but touching each other. They are then rubbed along the bar simultaneously, each from the middle towards its own end, where they are lifted, again replaced at the middle, and rubbed as before for a few times. This method, sometimes called *single touch*, is adopted when a very regular magnetism is required, such as in compass needles.

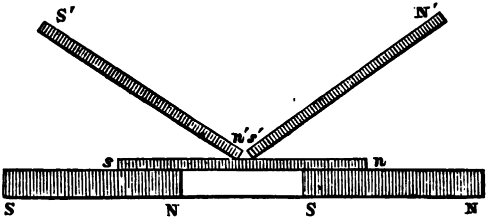

Fig. 8.—Magnetism by Friction.

Double touch. The disposition of the magnets in this case is the same as in *divided touch*, except that the rubbing poles are kept from touching each other by a small piece of some non-magnetic substance, such as wood. The rubbing magnets are then moved together from the middle to one end of the bar and (without lifting) back again to the other end, and so on, backwards and forwards for a number of times. Care must be taken not to allow either pole to leave the bar during the process, and each half must be rubbed the same number of times. This method, which communicates a very powerful magnetism, is used for thick bars, but it sometimes gives rise to *consecutive* poles, as if the bar were composed of say three magnets, the middle one lying in a direction opposite to the other two.

For horse-shoe magnets, proceed as in *single touch*, rubbing the poles of the induced magnet from the ends to the curve, or *vice versa.*

CHAPTER II.

TERRESTRIAL MAGNETISM.

13. Why should a freely-suspended magnet point north and south? In order to explain this and many other phenomena of a like nature, it is supposed that the earth is an immense magnet, having N. and S. magnetic poles and a neutral line just as any other magnet. The magnetic poles of the earth are near its terrestrial poles, but do not coincide with them. Now, as the needle is not acted on by the earth's terrestrial poles, it will not point to them; that is, it will not point exactly north and south, and, in fact, does not so point except in a few places.

14. **Declination.** A straight line at any place joining the N. and S. points of the horizon, as indicated by the needle, is called the *magnetic meridian* of that place, just as the corresponding line joining the true N. and S. points is called its geographical meridian. The freely-suspended magnet always comes to rest in the magnetic meridian. The angle between the geographical and magnetic meridians is called the *declination* or *variation* of the needle, which for this reason is sometimes called the declination needle. The declination of the needle is different at different places; thus at Paris it is about 19° W., at London about 20° W.; that is, at London the needle points 20° west of true north. Nor is the declination at all times the same at the same place. It was about 3° E. in London in the year 1600, from which time it moved gradually westward till the year 1818, when it was 24½° W., since when it has been moving eastwards. The mariner's compass used in steering ships is a declination needle. In ascertaining the meridian of any place by means of the compass, the necessary correction must be made for the declination of the place.

15. **Inclination.** A magnetic needle freely suspended on a horizontal axis, so as to be capable of moving only vertically, is called a *dipping* needle. Such a needle when at rest is not horizontal. When in the magnetic meridian, the angle made by the dipping needle with the horizon is called the *dip* or *inclination* of the needle. The amount of dip varies at different places and at different times at the same place. Its amount in London at present is about 67°.

16. **Magnetic equator and poles.** The magnetic equator *is a line drawn round* the middle of the earth through those *places that have no* dip. It is a curved line crossing the

terrestrial equator twice—once in the Gulf of Guinea and once near the middle of the Pacific Ocean. The dip increases from (0° at) the magnetic equator to (90° at) the poles, where the needle is vertical—its N. pole pointing downwards at the N. magnetic pole, which is situated in Boothia Felix 70° 5′ N., 96° 45′ E. The S. magnetic pole, which is believed to be S.W. of Australia, has not yet been reached. The declination needle is at rest in all positions at these poles.

17. **Magnetic intensity** is simply another name for magnetic strength. We have seen that the earth's magnetic intensity is both horizontal, as shown by the declination needle, and vertical, as shown by the dipping needle. The resultant of both horizontal and vertical is called total intensity.

18. **Why do we consider the earth a magnet?** Because it possesses magnetic properties; it acts upon a magnetic needle as another magnet would (1) in *directing the needle.* Suspend a magnetic needle over a bar magnet, with the centre of the needle exactly above the centre of the magnet; the needle will arrange itself parallel to the magnet, just as it would arrange itself parallel to the earth's lines of magnetic force if the magnet were not there. Turn the magnet horizontally round its centre; the needle will follow, endeavouring to preserve the parallelism. It may be objected that the N. pole of the needle points to the S. pole of the magnet, but to the N. pole of the earth. How is this, if the earth is a magnet? Simply because the poles of our magnets in this country are incorrectly named. What we call the north pole should be called as in France the south. The difference, however, is only in name.

(2) *The earth acts like a magnet on the dipping needle.* In the last experiment both magnet and needle remained parallel, because the needle was suspended over the neutral line of the magnet; if gradually moved towards either pole, the needle will dip more and more, till it becomes vertical when exactly over the pole.

(3) *The earth acts by induction like a magnet.* If we take a bar of soft iron—a poker will suit—and hold it in the magnetic meridian in the angle of dip, it will at once become a magnet, with the end pointing downwards its N. pole. Remove it from this position, it loses its magnetic properties; completely reverse it (still keeping it parallel to the dipping needle), the end pointing to the earth is again a N. pole. These rapid magnetic changes are owing to the absence of coercive force. A steel bar is not so changeable, nor are its poles thus reversible when subject to the earth's inductive action. Coercive force may be imparted to the iron by giving it a few sharp blows on one end with a hammer, and the magnetisation of the steel

may be hastened by rubbing it with soft iron. Loadstone is supposed to have acquired its magnetic properties through the magnetism of the earth acting on it for ages. Iron railings, tools in workshops, fire-irons kept in a vertical position, will generally be found magnetic for the same reason.

19. The earth's magnetic force simply directive. Unlike an ordinary magnet, the earth has no magnetic power to draw a magnet nearer itself; its action is simply directive. In other words, the magnetic poles of the earth which give direction to a magnetic needle are incompetent to produce a motion of translation. This can be readily proved by floating a magnet on water. A magnetised sewing needle, supported on a piece of cork, for instance, comes to rest in the magnetic meridian, but exhibits no tendency to move towards either pole of the earth, whereas it would follow a bar magnet over the surface of the liquid. This latter motion, as explained in Arts. 9 and 7, arises from the attracting poles being nearer each other than the repelling poles. But owing to the immense distance of the earth's poles from the needle, they may be considered as equally distant from both its ends, so that the intensity with which one end is attracted is exactly equal to the intensity with which the other is repelled; hence the centre of the needle exerts no lateral strain on its point of support, it simply turns round.

CHAPTER III.

FRICTIONAL ELECTRICITY.

20. Thales, a celebrated Greek philosopher, who lived about 600 B.C., noticed that when amber was rubbed it acquired the power of attracting light and dry bodies. This appears to have been the only fact known in connection with the science of Electricity till about the year 1600 A.D., when Dr. Gilbert, of Colchester, physician to Queen Elizabeth, showed that rubbed glass, wax, sulphur, &c., possess this property as well as amber. A rod of glass, for instance, rubbed with a piece of silk, both glass and silk being quite dry, will attract bran, hair, sawdust, &c. The unknown principle, or species of life, which Thales supposed to animate rubbed amber, Gilbert called Electricity, from *electron*, the Greek word for amber; and a body which possesses, like rubbed amber, the power of attracting light substances is said to be *electrified*, *excited*, or *charged* with Electricity.

21. *A very simple* experiment will make us acquainted with

some of the ways in which the electricity of an excited body manifests its presence. Hold a piece of stout brown paper, a little larger than a school slate, before the fire till it is quite hot, then lay it on a table and rub it briskly a few times with the open hand, or with a clothes-brush.

I. Lift the paper by one of its corners ; it will be found to adhere strongly to the table.

II. Hold it over a collection of light substances, such as cuttings of paper, bran, sawdust, it will attract them like the glass of the last Art.

III. Bring the paper near a wall, it will rush towards and adhere to the wall.

IV. Bring it near the extended fingers, it will move towards them, sparks with a crackling sound passing between the fingers and paper.

V. Hold the paper over the head of a person having dry hair (or over a doll's head), the hair will stand on end pointing to the paper.

VI. Hold the paper before the face, you will experience a sensation as if a cobweb was drawn across it.

22. Conductors and non-conductors. Friction generates electricity in all bodies. Why then will a metal rod, when held in the hand and rubbed, exhibit none of the properties of rubbed glass or rubbed paper? Because, though the particular part of the glass rod that is rubbed becomes electrified, yet, owing to the resistance of glass to the passage of electricity through it, the electricity thus generated is confined to the rubbed part ; while the metal offering almost no resistance, the electricity instantly spreads itself over it, and escapes through the hand to the earth. The metal is said to *conduct* the electricity to the body, and the body to the earth, to which electricity always endeavours to escape. *Substances which possess in a very high degree the capacity of transmitting the electric power, or condition, are called conductors. Substances which possess in a very high degree the capacity of intercepting it, are called non-conductors.*—Tyndall, Notes, *Elect. Phen.*, p. 11.

No body is either a perfect conductor or a perfect non-conductor. The best conductor offers some resistance to the transmission of electricity ; the best non-conductor transmits some. In the following lists the substances are arranged approximately according to their conducting powers, commencing with the best of each kind. The metals, for instance, are better conductors than charcoal, and shellac a better non-conductor than amber.

Conductors.

The metals.
Charcoal.
Acids.
Water.
Living vegetables.
Flax.
Living animals.
Flame.
Moist earth.

Non-conductors.

Dry air.
Paraffin.
Shellac.
Amber.
Resins.
Sulphur.
Wax.
Glass.
Silk.
Gutta-percha.
India-rubber.
Dry wood.
Wool.
Feathers.
Dry paper.

Non-conductors were formerly called *electrics,* because they could be electrified by friction *when held in the hand.* Conductors were called *non-electrics,* because they could not be so electrified. This division is unsound, for a metal rod may be electrified by friction if held by a glass handle, the glass preventing the escape of the electricity from the metal. In this case the metal is said to be *insulated* by the glass, which is thence called an *insulator. A body is insulated when it is connected with the earth by non-conductors only.* Conductors then can be electrified by friction when insulated ; non-conductors insulate themselves.

23. Electric pendulum. The electric pendulum or pith-ball electroscope (Fig. 9) consists of a convenient stand, on which is fitted a glass rod having a bent arm, from the extremity of which a pith-ball is suspended by means of a silk thread. The glass and silk insulate the ball.

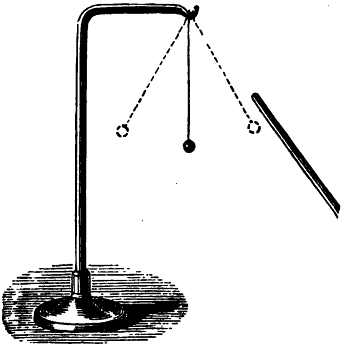

Fig. 9.—Electric Pendulum.

24. Two kinds of electricity. I. Electrify a rod of dry sealing wax by rubbing it with warm flannel, and bring the rubbed wax near the pith-ball of the pendulum. The wax will attract to itself, and part with some of its electricity (Art. 31) to the ball, but as soon as they touch, this attraction will be changed to repulsion, which will continue as long as wax and ball retain their charges. Hence *the electricity produced on wax by rubbing it with flannel repels itself.*

II. Rub a dry glass rod with warm silk, and present it to a similar ball. The ball, as before, will be first attracted and then repelled, showing that *the electricity produced on glass by the friction of silk repels itself.*

III. Now if the two balls—the one repelled by rubbed silk, the other by rubbed sealing-wax—be brought near each other, each ball will attract the other. The experiment may be varied thus :—To the ball which has been repelled by the excited glass rod present the excited rod of sealing-wax. The sealing-wax will first attract the ball and then repel it. When thus repelled by the excited sealing-wax, it will be attracted by the excited glass, and so on. From these experiments we conclude (1) that *there are two kinds of electricity which agree in their power of attracting light substances,* and (2) *that each kind repels itself and attracts the other.*

25. Action of rubbed bodies on each other. The same conclusions might have been drawn from the action of rubbed bodies on each other.

I. Place a glass rod which has been previously rubbed with silk in a wire or paper stirrup (Fig. 10). Bring the end of another similarly excited glass rod gradually near the end of the suspended one. The suspended rod will be repelled. Hence *rubbed glass repels rubbed glass.*

II. Remove the glass rod, and in its place put a stick of sealing-wax or resin which has been rubbed with flannel. Bring a similarly excited stick of wax near the suspended stick, the latter will be repelled. Hence *rubbed wax repels rubbed wax.*

III. Leave the excited wax in the loop. Bring the excited glass near it. The wax will be attracted. Hence *rubbed glass attracts rubbed wax.*

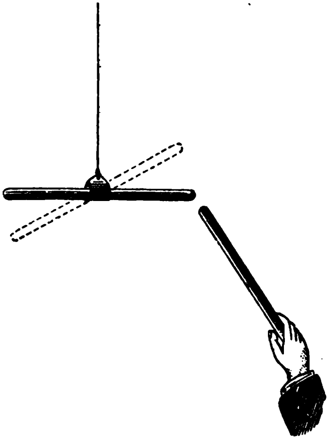

Fig. 10.—Excited Glass Rod repelling Similar Rod.

IV. Leave the excited glass in the loop. Bring the excited wax near it. The glass is attracted. Hence *rubbed wax attracts rubbed glass.*

If by a vitreous body we mean one which when excited exhibits the same kind of electricity as glass rubbed with silk, and by a resinous body we mean one which when excited exhibits the same kind of electricity as wax rubbed with flannel, then, if for the glass of the previous experiment we substitute *any vitreous body* whatever, such as crystals, and for the wax *any resinous body* whatever, such as resin or amber, we shall in every case find that *rubbed resinous bodies repel each other, rubbed vitreous bodies repel each other, but rubbed vitreous and rubbed resinous bodies attract each other.* This statement is conveniently summarised in the law of attractions and repulsions—viz., **like electricities repel each other; unlike attract.** As is indicated by this law, the attractions and repulsions take place between the two electricities with which bodies are charged, not between the particles of matter of which they are composed.

26. Positive and negative. The terms vitreous and resinous are now seldom used, because, by employing suitable rubbers we can obtain the electricity of sealing-wax from glass, and the electricity of glass from sealing-wax. Instead of vitreous we now employ the term *positive*, and instead of resinous *negative*. "Positive" denotes the kind of electricity produced on glass by the friction of silk; "negative," the kind produced on sealing-wax by the friction of flannel. These terms admit of a convenient contraction, +E standing for positive electricity, and − E for negative.

27. Both electricities simultaneously produced. That both kinds of electricity are produced at the same time may be shown by a person insulated on a stool with glass legs striking with a cat-skin another person similarly insulated. The striker will be positively, and the person struck negatively, electrified. Sparks may be drawn from both by presenting the knuckle to them.

The rubber and the rubbed bodies are *equally* excited, as may be shown by the friction of two discs, one of glass, the other of brass covered with silk. Neither glass nor silk (though both insulators) gives evidence of electrical excitement as long as they are in contact; hence the opposite electricities produced must be equal in amount, since they exactly neutralise each other.

The kind of electricity produced by the friction of two bodies depends very largely on the nature of their surfaces. Thus smooth glass becomes $+^{\text{ly}}$ electrified when rubbed with silk, rough glass $-^{\text{ly}}$. In the following list each substance, generally speaking, becomes $+^{\text{ly}}$ electrified when rubbed by any of the succeeding substances; $-^{\text{ly}}$ when rubbed by any *of the preceding*:—

Cat's fur.
Flannel.
Smooth glass.
Cotton.
Paper.
Silk.
The dry hand.
Wood.
Metal.
India-rubber.
Sealing-wax.
Amber.
Sulphur.
Gutta-percha.
Gun-cotton.

Thus smooth glass becomes $+^{ly}$ electrified when rubbed with silk, and $-^{ly}$ when rubbed with cat's fur.

28. Theory of Electricity: Electric Fluids. What, it may be asked, is this electricity of which we have been speaking? No one has yet been able to answer this question. Till this is done satisfactorily, we may employ the provisional conception known as the *theory of electric fluids.* It will enable us to classify our facts, though it is not to be regarded as demonstrated. *According to this theory, electrical attractions and repulsions arise from two invisible fluids, each self-repulsive, but both mutually attractive. The fluids are supposed to be mixed together to form a compound neutral fluid in unelectrified bodies.*

The act of electrification by friction consists in the forcible separation of the two fluids, one of which is diffused over the rubber, and the other over the body rubbed.—Tyndall, Notes. p. 11.

29. Electric induction. Electrical *induction* or *influence* consists in the action of electricity upon other electricities near it; it has been defined as "the decomposition of the neutral electric fluid by the mere presence of an electrified body." The varied phenomena of induction may be illustrated by means of an insulated brass cylinder A B (Fig. 11), from which are suspended by cotton threads a few pairs of pith-balls. When

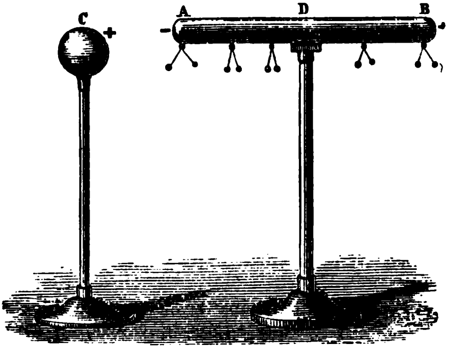

Fig. 11.—ELECTRIC INDUCTION.

the cylinder is brought near the insulated conducting sphere C, charged with say +E, the balls of the different pairs diverge, showing that each pair is charged with the same kind of electricity. The amount of divergence decreases from the pair nearest the excited sphere to a point D, near the middle of the cylinder, where it disappears ; beyond which point the divergence gradually increases as we approach the end farthest from the ball. An excited stick of sealing-wax brought near the balls at A, repels them; if brought near those at B, it attracts them. Hence it is inferred that the +E of C has separated the fluids of A B, attracting its negative fluid, and repelling its positive.

If now we touch B with any uninsulated conductor, say the finger, its +E will flow through the finger and body to the earth, and if we remove first the finger, and then C, the cylinder will contain only free negative electricity, and is said to be *negatively electrified by induction.* As long as C is kept near A B, the +E of B is free to act on all surrounding bodies, so that if a cylinder similar to A B is placed near to and in a line with it, the free +E of B will act by induction on this cylinder just as C acted on A B. In fact a series of such cylinders may be thus excited, having their ends next C positively electrified, and their other ends negatively. On removing C the diverging balls collapse, owing to the recombination of the separated electricities, which must therefore have been equal in amount (Art. 27).

But before doing so, it may be asked what has become of the −E of A. It is held there by the attraction of the +E of C, which it in turn attracts so heartily as to be incapable of exerting any other inductive action. Thus situated, it is said to be *fixed, bound,* or *latent.*

30. If we had brought A B into contact with C, part of the +E of the latter would have spread itself over the cylinder, which would then be said to be electrified by *conduction* (Art. 24). Conduction charges a body with the same kind of electricity as the excited body; induction with the opposite kind. A body can be charged by conduction only when insulated ; when charged by induction it must be uninsulated, at least momentarily.

Electric induction in many respects resembles magnetic. (Compare Art. 9.) They differ, however, in some points. For instance (1), the neutral line of a uniform magnet is always at or near its middle, whereas the neutral line at D gradually moves towards A as C is brought nearer it, till when contact takes place conduction ensues. (2) A magnet touching an iron bar induces magnetism in it without itself sustaining any loss of magnetic power; an electrified body parts with some of its charge by conduction to any body it touches. (3) Both magnetic fluids are always present in the same body in equal quantities. They cannot be insulated from each other. If, however, A B excited by the inductive action of C be capable of division into two parts, A D and B D each having a glass leg; on separating the parts in presence of C, A D will be found negatively, and B D positively, electrified.

31. **Electrical attractions and repulsions** all depend upon induction. Take the case of the excited glass rod presented to the pith-ball of the pendulum (Art. 24). The glass being $+^{ly}$ electrified acts by induction on the fluids of the ball, attracting its $-E$ to the side next itself, and repelling its + to the farthest side. The opposite fluids (the + of the glass and the − of the ball) are then nearer each other than the similar fluids (the + of the glass and the + of the ball), so that the ball is more strongly attracted than repelled. Contact with the $+E$ of the glass neutralises the small induced charge of $-E$ on the ball, thus leaving it like the glass $+^{ly}$ excited, in consequence of which it is repelled. It thus appears that neutral bodies are excited by induction before being attracted. (Compare Art. 9.)

32. **Electroscopes** are instruments used to test the presence or absence of free electricity, and the kind with which an excited body is charged. The pith-ball pendulum is an electroscope (compare Art. 5). When we wish to test the electric state of a body we positively electrify the ball of the pendulum in the manner just explained, and present the body to be tested to it. If repulsion takes place, we may be sure the body is $+^{ly}$ electrified (Art. 25). But suppose the ball is attracted, we learn nothing further than that it is either unelectrified or electrified $-^{ly}$ (Art. 24, III.; compare Art. 5). For this reason repulsion is preferred to attraction as an electrical test.

33. **The quadrant electroscope** (Fig. 12) generally used in connection with the machine, consists of a metal stem, to which a straw with a pith-ball at its free end is attached. When the stem is inserted in a highly excited body, the straw and stem, being similarly electrified, repel each other, causing the straw to move round a graduated arc, thus measuring the relative strength of the charge by the degree of its divergence from the vertical.

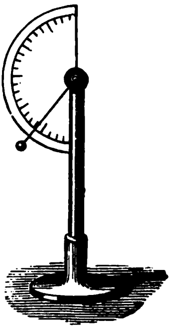

Fig. 12.
QUADRANT ELECTROSCOPE.

34. The gold leaf electroscope (Fig. 13) for testing feeble charges, consists of a glass jar (or globe) on a wooden stand. The neck of the jar is fitted airtight with a wooden stopper, through which passes an insulated brass rod, terminated above by a brass disc (or ball), while from its lower extremity depend two strips of gold leaf or Dutch metal. Instead of gold leaf, two straws or two pith-balls suspended by linen threads are sometimes used. We have thus the *straw electroscope* and the *pith-ball electroscope.*

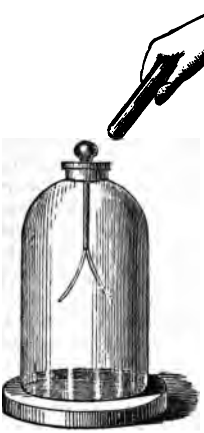

Fig. 13.—Gold Leaf Electroscope.

To use the instrument, we bring the body whose electric state is to be tested near its knob (or disc). If the leaves remain stationary, we may conclude that the body is unelectrified, for otherwise they would diverge under its inductive influence.

In order to determine the *sign* of the E to be tested, we previously electrify the leaves by induction. This is done in the following manner:—First bring an excited glass tube near the knob. The +E of the glass will act by induction on the knob, rod, and leaves, attracting their −E to the knob, and repelling their +E to the leaves, which will in consequence diverge. If we now touch the knob with the finger, it will afford a ready passage for the flow of this free and repelled +E from the leaves to the earth, and as the −E is *fixed* on the knob by the + of the glass, the leaves are no longer under electrical excitement, and consequently collapse. Next remove the finger, and then the glass tube and the −E which was confined to the ball will spread over ball, rod, and leaves, which latter will again diverge, this time with −E. The instrument is now ready for use. A $+^{ly}$ excited body brought near the knob will attract the −E from the leaves, and they will collapse; a $-^{ly}$ excited body will repel the −E of knob and rod into the leaves, causing them to diverge still more. The body to be tested should not touch the knob, as the charge thus communicated to the leaves might cause them *to diverge so rapidly* as to tear them.

35. Proof plane. Samples of electricity may be carried from place to place, or presented to the electroscope, by means of the *proof plane* or *carrier*, which consists of a small conductor with an insulating or insulated handle. It may be a disc of gilt paper with a handle of shellac, or of tin-foil with a straw handle fastened to it with sealing-wax ; even a brass button suspended by a silk thread will frequently suffice.

36. Distribution of free electricity on the surfaces of conductors. That free E is confined exclusively to the external surfaces of conductors may thus be proved. Electrify a hollow insulated sphere having a circular orifice. A proof plane, after being applied to the interior surface of the sphere, is found on being tested by the electroscope to be unelectrified, the exterior surface at the same time giving evidence of electrical excitement when similarly tested. It follows from this that a hollow sphere will accept as great a charge as a similar solid one.

A pretty and convincing experiment, devised by Faraday, proves the same thing. His "butterfly net" (Fig. 14) consists of a cone-shaped bag of gauze or fine linen attached to a metal ring fixed on an insulating stand. When the extended bag is electrified, it is found (by means of the proof plane and electroscope) that the exterior surface only is excited, and even on turning it inside out, by means of a silk thread fastened to the apex, the E is found only on that which is now the outer surface, and which before was the inner.

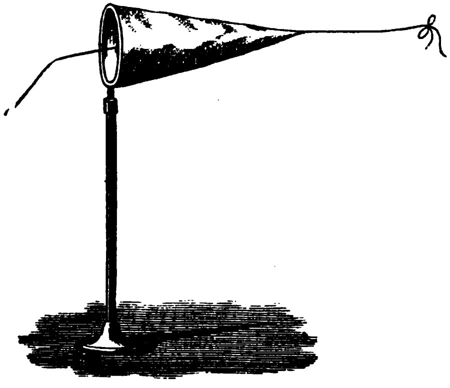

Fig. 14.—FARADAY'S BUTTERFLY NET.

But though the free E is confined to the outer surface of conductors, it is not *equally* distributed ever them, except in the case of a sphere. It has, on the contrary, a tendency to accumulate on projections, points, or corners ; on a cube, for instance, along the edges, especially at the angles ; on an egg, at the ends, &c. The *density*, *i.e.*, the depth, of E is greatest at these places, and owing to its self-repellent character, its *tension*, *i.e.*, its tendency to escape, is here also greatest.

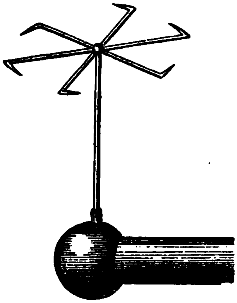
Fig. 15.—Electric Whirl.

37. Effect of points. Hence there is a constant escape of E from conducting points. Thus, if the *electric whirl* (Fig. 15) be placed on the prime conductor of a machine at work, the escape of the fluid from its points will, by its reaction, cause the whirl to rotate in the opposite direction, just as a bullet reacts on the gun from which it is shot. The electrical wind from the points affects the flame of a candle, and may be felt when the face is brought near. Flames act like points in dissipating electricity. Apparatus designed to retain an electric charge are made quite smooth and round, without sharp curves, lines, or points ; but, notwithstanding these precautions, owing to the imperfection of the best insulators and the conducting power of the surrounding air when moist, excited bodies gradually part with their E.

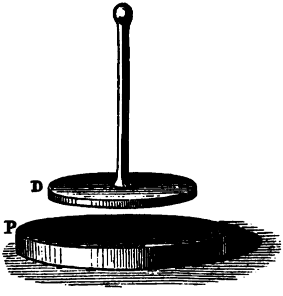

Fig. 16.—Electrophorus.

38. The electrophorus. Volta's electrophorus (Fig. 16) is used for the production of electricity in small quantities. It consists of two parts, (1) the *plate* (P), a metallic mould filled with some material easily excited by friction, such as resin or shellac; and (2) the *cover* (D), a movable polished metal disc with an insulating handle.

To use the instrument, rub the resin briskly with flannel or catskin, and place the cover on it. Touch the disc with the finger for an instant, and then lift the cover by its handle. On presenting the knuckle to it, a bright spark passes, causing a stinging sensation. The spark is accompanied by a crackling noise. The preceding process may be successfully repeated for a considerable number of times in dry air, without again exciting the resin.

The friction generates −E on the resin, which acts by induction on the cover, attracting its + to the lower surface, and repelling its − to the upper. The finger conducts the latter to the earth, leaving on the cover only +, which escapes in the form of a spark to the knuckle, thus discharging the cover. As the plate has parted with none of its E to the cover, it again acts inductively on the disc when placed on it. But why *inductively* when the disc is placed *on* it? Because the resin is a non-conductor.

The mould is not essential to the *plate*, which may be simply a disc of gutta-percha or vulcanised cloth. Even a piece of brown paper will serve for plate, and a toy tin-plate, with handle of sealing-wax, for cover.

39. Condenser. An electric condenser usually consists of two conductors separated by a dielectric,[*] one conductor being insulated and the other not. The conductors are generally made of metal, and the dielectric of glass.

Its action may be understood from Fig. 17, where A and B are the conducting plates, on insulating supports, of which A, connected with the prime conductor of an electric machine, is called the collecting plate, and B, connected with the earth (say by touching it with the finger), the condensing plate. C is the glass dielectric. It will be convenient to call the face of

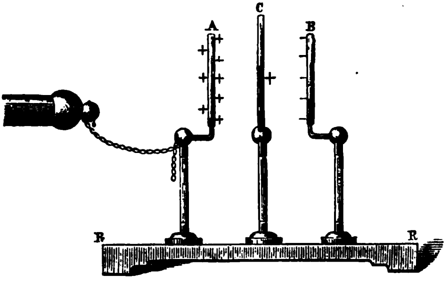

Fig. 17.—CONDENSER.

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[*] The medium through which induction is propagated, as air, glass, resin, &c., is called the *dielectric.*

each conducting plate next the glass its *front*, and the other face its *back*.

On working the machine, the +E of its prime conductor diffuses itself over A, whose electric density, supposing B and C absent, would always be equal to that of the prime conductor. When A and B are brought into contact (which is done by sliding their supports along a groove in R R) with their respective sides of C, the neutral E of B is decomposed by the influence of A, −E being accumulated on its front, while its + passes to the earth. The −E on the front of B is not only bound by the + of A, but it in turn reacts on A, attracting its positive to the side next the dielectric. This rush of the + of A to its front lessens the density of the fluid on its back. To restore equilibrium, fresh E flows from the machine, which by induction decomposes a fresh quantity of B's neutral fluid, causing a new accumulation of − on the front of B, and in consequence a new accumulation of + on the front of A; and this series of actions and reactions will continue till the flow of E from the machine renders the density of the fluid on A's back equal to that on its front. The electric density on the face of A is thus increased, and its capacity for storing up electricity on its surface enormously augmented, owing to the proximity of B. Hence the "condensation of electricity consists in increasing the capacity of a conductor by bringing near it another conductor connected with the earth."—Deschanel's *Nat. Phil.*, vol. iii., p. 445.

40. **The fulminating pane** is a simple form of condenser suitable for strong charges. It consists of a glass plate fixed in a wooden frame, like a writing slate, and coated on both sides, to within a couple of inches of its edge, with tinfoil. From the under coating there runs along the intervening glass to a conducting ring in the frame a strip of tinfoil, and from this ring stretches a metallic chain, connecting it with the earth. The pane is charged by connecting the upper (insulated) coating with the machine at work.

41. An amusing experiment (for the spectators at least) consists in the attempt to lift a coin from the upper cover with one hand while the other is in contact with the lower coating, for the body thus connecting the opposite coatings receives a powerful shock from the recombination of their respective charges through it.

Condensers may be discharged without inconvenience by means of the *jointed discharger* (see Fig. 18), which consists of two brass rods hinged together and insulated by glass handles. *To discharge the condenser* (Fig. 17) we take a handle in each hand, and bring one of the knobs of the discharger into contact with B (the uninsulated plate). On bringing the other knob round to A the discharging spark passes harmlessly.

42. Discovery of the Leyden jar. In October, 1745, Von Kleist, of Pomerania, electrified a flask of alcohol by connecting a nail which passed through its cork with the prime conductor of a machine at the same time that he held the flask in his hand. On touching the nail he received a violent shock.

In January, 1746, Cuneus, of Leyden, wishing to electrify water, placed it in a glass flask into which dipped a metallic chain hanging from the prime conductor of a machine. Holding the flask in his right hand, he was about to lift the chain out of the water with his left, when, to his consternation, he experienced a shock such that, according to his own account, it took him two days to recover, nor would he for the crown of France expose himself to a similar one.

Kleist contests with Cuneus the honour of giving his name to the jar, but as the Leyden philosophers were the first to recognise that only the person who held the flask in his hand felt the shock, it has been named from their city.

These first forms of the Leyden jar will be recognised as modified condensers; the hand supporting the phial acting the part of a condensing plate, the water that of a collecting plate, the glass vessel being the dielectric.

43. Leyden jar. The Leyden jar (Fig. 18) as at present constructed consists of a glass jar of any convenient size, coated inside and out with tinfoil for about four-fifths of its height. The neck is closed with a cork or wooden stopper, through which passes a metallic rod, terminating above in a brass knob, and below in a brass chain, which connects it with the inner coating. Instead of the chain and interior coating the jar may be filled with metallic-foil or thin leaves of copper.

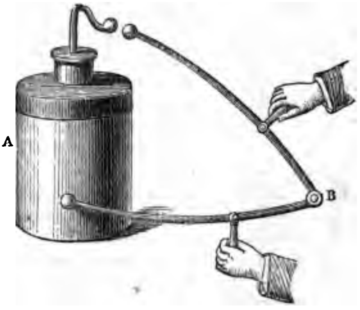

Fig. 18. { A, LEYDEN JAR.
B, JOINTED DISCHARGER.

The jar, which is a form of condenser, is charged by connecting one of its coatings (conductors) with the source of electricity, and the other with the earth. When it is held in the hand by the outer coating and the knob presented to the conductor of the machine, $+E$ passes from the latter to the knob, and thence by the rod and chain to the inner coating, which thus, becoming $+^{ly}$ electrified, acts by induction upon the outer, repelling its + through the hand to the earth, and attracting its − to the side next the glass. If we had presented the outer coating to the machine, holding the jar by its knob, the outer would have become $+^{ly}$, and the inner $-^{ly}$ electrified.

The theory of the jar is thus seen to be identical with that of the condenser. (See also Art. 47.) Like it also, the jar can be discharged either slowly or instantaneously. In using the discharger care must be taken to touch the outer coating first, otherwise the discharge may break the glass. (See Art. 41.) The jar is discharged slowly by what is known as alternate contact, *i.e.*, touching the knob and outer coating alternately with a conductor, the jar being insulated. At each contact a spark passes.

44. Residual charge. After instantaneous discharge we can generally obtain a second, but much smaller, spark by again connecting the coatings. This is called the *secondary discharge*, and the electricity producing it is called the *residual charge*. It is produced by the liberation of those parts of the opposite fluids which in their endeavour to recombine through the glass had penetrated it to a very small depth.

45. Jar with movable coatings. That the fluids of the jar reside on (or in) the glass, rather than on the surface of the coatings next it, is shown by the jar with movable coatings. A glass vessel (A, Fig. 19) shaped like a tumbler (one of good flint glass will suit very well, see Art. 37). serves as jar, while the coatings may be of zinc or tin. After charging this jar in the ordinary way, insulate it, and lift out the inner coating B by its insulating handle, and then the glass vessel. After discharging both coatings of any electricity they may contain, when the jar is put together again it will give almost as strong a shock as if the coatings had not been discharged. The greater part of the original charge must therefore have been in the glass.

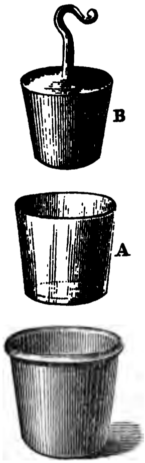

Fig. 19.
LEYDEN JAR WITH MOVABLE COATINGS.

46. Leyden battery. When a very strong charge is required, we may employ either a large jar or a number of small jars acting as one. The latter arrangement is known as a Leyden battery. It consists of a number of Leyden jars resting on a metallic surface in free communication with the earth, and having their inner coatings or knobs connected by brass rods. The capacity of the battery is the sum of the capacities of its component jars.

47. Cascade battery. In charging a Leyden jar, for every spark of +E which passes from the machine to its knob there passes a corresponding amount of +E from its outer coating to the earth (Art. 43), either silently, as when the jar is in contact with a conductor, or by spark when nearly so. Now suppose that by means of a chain we connect the outer coating of our jar with the knob of another, both being insulated, the +E of the first, instead of escaping to the earth, will pass along the chain to the knob, and act upon the second jar just as the machine does upon the first. The +E thus repelled from the second jar may be similarly utilised in charging a third, and so on, taking care that all the jars are insulated except the last, which should be connected with the earth. Charge by cascade corresponds to the charging of the cylinders (Art. 29), the machine playing the part of the excited ball, the glass of the jar that of the air separating the cylinders, while the outer coating of the first jar and the inner of the second taken together act as the first cylinder, the outer coating of the second jar and the inner of the third as the second cylinder, and so on. The battery is discharged by connecting the knob of the first jar with the outer coating of the last.

48. Electric machines. The first "electric machine" was invented by Otto Guericke, burgomaster of Magdeburgh. It consisted of a ball of sulphur, which was rubbed with the hands. The sulphur became $-^{\mathrm{ly}}$ electrified, the corresponding +E escaping through the body to the earth. A glass globe was afterwards substituted for the sulphur ball.

The principal parts of an electric machine are the rubber, the body rubbed, and the *prime conductor*, a part of the instrument designed to collect the electricity as generated, and to part with it as required. Electric machines, as usually made now, are known as cylindrical or as plate machines, according as the rubbed surface consists of a cylinder or a plate of glass. The former are cheaper, more easily made and managed; the latter presenting both sides of the glass to the rubber are more powerful.

Fig. 20 represents a plate machine. G is a circular plate of glass which is turned by means of the handle A. This handle is a prolongation of the axis that supports the plate on wooden uprights. As the plate revolves, two cushions H H made of leather, stuffed with horse-hair, are pressed tightly against it by means of screws. These cushions are called the rubbers, and are generally coated before use with an amalgam, which considerably increases the production of electricity.

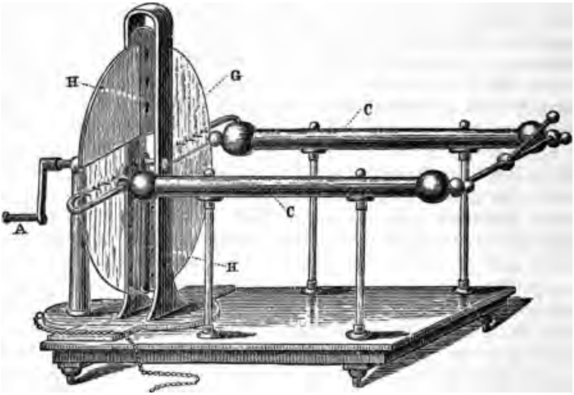

Fig. 20.—Plate-Glass Electric Machine.

C C are metallic conductors (usually brass cylinders) insulated on glass legs. To these conductors, collectively called the *prime conductor*, are fixed two brass rods of a horse-shoe shape, which bend round the plate, and are provided with points projecting towards it.

When the plate is turned, the friction of the rubbers against it generates −E on them, and +E on the glass. A chain connecting the rubbers with the earth allows their −E to escape, while the +E of the glass is carried round as far as the metallic points. Here it acts by induction upon the prime conductor, attracting its −E, which in consequence streams off the points, neutralising the +E of the glass, and leaving the conductor $+^{ly}$ excited, and as the revolution of the plate is continually generating a fresh supply of +E, there is a corresponding continuous flow of −E from the points, leaving the prime conductor more and more highly excited by the remaining +E. It thus appears that the conductor is charged, not by imparting +E to it, but by withdrawing its −E. That the electricity generated by the rubbers may be carried round as far as the points without loss, flaps of silk envelop the intervening portion of the plate. Before using the machine, it should be thoroughly dried and freed from dust by rubbing it with a warm dry cloth in presence of a fire.

49. Experiments: *Physiological effects.* I. The face of a person near a machine at work experiences a sensation as if spiders' webs were touching it. Accompanying this is a peculiar sulphurous smell.

II. When a person standing on an insulating stool, *i.e.*, a stool with glass legs, presents his knuckle to the prime conductor, its $+E$ attracts the $-E$ of his body. When the tension of these opposite electricities becomes sufficient to overcome the resistance of the intervening air, they unite with a snapping noise and a spark, causing a prickling sensation in the knuckle. When short the spark is straight, at a few inches' distance it becomes curved, and if longer of a zig-zag direction.

III. Still remaining on the stool, place the hand on the prime conductor, or hold a conducting body fixed to it. As the machine is turned, a tingling sensation is felt, the hair, especially if dry, stands on end, and a spark will pass from any part of the body to a conductor, say the finger of a bystander, presented to it.

IV. If the first of a chain of persons holding each other tightly by the naked hand touch the knob of a charged Leyden jar, which is held in the hand by the last person of the chain, all will simultaneously experience a shock.

V. A mouse may be instantaneously killed by discharging a jar through its head. Care should be taken not to experiment with a large jar completely charged. Franklin was twice struck senseless by the electric shock, and Dr. Tyndall, from accidentally touching a wire leading from a battery, was rendered completely unconscious. He says—"For a sensible interval life was absolutely blotted out, but there was no trace of pain." Dr. Tyndall regards this "as an experimental proof that people killed by lightning suffer no pain."

VI. When a living frog is held near a machine at work, every time a spark passes from the conductor its body is violently convulsed. The $+E$ of the machine electrified the frog negatively by induction. The spark instantaneously discharging the machine, thereby relieved the frog from its inductive influence, when a rapid rush of $+E$ from the earth to neutralise the $-E$ remaining in the animal's body produced the shock causing the twitching.

50. *Deflagrating effects.* I. Standing on an insulating stool, present the knuckle to a gas jet. A spark will pass, kindling the gas.

II. When a candle which has just been extinguished, leaving a long "snuff," is presented to the prime conductor, the passage of the spark through the smoke to the wick relights the candle.

III. Sprinkle over a bit of cotton or piece of tow a little powdered resin, and tie the cotton over one of the knobs of the discharger. On bringing this knob near the ball of the Leyden jar, the other knob being in contact with its outer coating, the spark discharging the jar will ignite the cotton.

IV. An ordinary electric discharge takes place too rapidly to kindle gunpowder, it merely scatters it about. But if obliged to pass through a wet string, its velocity is thereby so retarded as to give the powder time to ignite. Wires of platinum or iron, which are bad conductors of electricity, may be heated and ultimately fused by passing a strong charge through them.

51. *Mechanical effects: Influence of points.* I. Place a quadrant electroscope on the prime conductor, the pendulum is repelled. On taking a spark from the machine the pendulum suddenly falls, to rise again gradually as the conductor becomes again excited.

II. Bring the point of a steel sewing needle near the conductor, the pendulum immediately falls, and remains thus vertical as long as the needle is so pointed.

III. Try to take a spark from the machine, you fail; it is silently parting with all its energy to the little needle. In fact, the —E drawn from the earth, by the inductive action of the +E of the machine, passes in a stream from the fine-pointed needle to the prime conductor, neutralising its +E as soon as generated. (Compare Art. 48.) Substitute for the steel needle a rod of sealing-wax or other non-conducting substance, it produces no effect whatever.

IV. Were the needle fastened to the prime conductor, similar effects would be produced, no spark could be obtained. In this case the +E of the machine escapes from the point with such force as visibly to affect the flame of a candle, and with a powerful machine to extinguish it. The electric whirl has already been described (Art. 37).

V. Electrify the interior of a dry flint-glass tumbler by touching its parts with an excited conductor. Invert the tumbler over a number of pith-balls on a table. The balls will be alternately attracted and repelled by the glass.

VI. The following is a simple experiment of the same kind: Between two books lying on a table strew some dry bran. When a pane of glass is placed over the bran with its edges resting on the books, and briskly rubbed with a silk handkerchief, the bran will dance up and down between the table and glass.

VII. A Leyden jar discharged through a piece of card-paper perforates it. If the charge is sufficiently powerful, a plate of window-glass may be broken or a stick of wood split by the passage of the spark.

52. **Luminous effects.** If the preceding experiments are performed in the dark, the needle, whirl, and indeed all conducting *points* of the apparatus (such as links of chains, prongs of conductor, &c.), will be seen tipped with flame. This is called the "brush" discharge. Of course the electric spark ranks as a luminous effect.

53. **Atmospheric electricity.** To Franklin is due the honour of proving the identity of lightning and electricity. In an extract from the minutes of experiments made by him he enumerates the particulars in which lightning and electricity agree, and which led him to "propose the experiment of drawing down the lightning in order to ascertain its sameness with the electric fluid." He notes that the "electric fluid agrees with lightning in these particulars: 1, Giving light; 2, colour of the light; 3, crooked direction; 4, swift motion; 5, being conducted by metals; 6, crack or noise in exploding; 7, subsisting in water or ice; 8, rending bodies it passes through; 9, destroying animals; 10, melting metals; 11, firing inflammable substances; 12, sulphurous smell."

In June, 1752, in a field near Philadelphia, he flew a kite with a metallic point attached to it. The cord which held the kite was of ordinary pack-thread, to the lower extremity of which he fastened a door-key, and to the key a silk string, which he held in his hand, thereby insulating any electricity which might collect on the key as prime conductor. At first he failed to obtain any evidence of the presence of electricity from the key, but soon a falling shower wet the hempen cord, thus improving its conducting power, when he found that the key freely emitted sparks to conductors placed near it. Leyden jars were afterwards charged in this manner, and a spark from a similar apparatus, invented by Professor Richmann, of Petersburgh, killed him on the spot.

Franklin imagined that his kite drew the electricity from the clouds. Its effects are now known to depend on induction. (Art. 55) The air is almost always charged with electricity; in fine weather positively, at other times negatively.

54. **Lightning conductors** were first made by Franklin in 1760. They depend on the principle that of several conductors electricity always prefers to travel through the best. A lightning conductor consists of the part above the building called the *rod*, the part connected with it called the *conductor*, and the part in the ground. These parts should be made of

metal, screwed or soldered together, the whole forming one continuous conductor, without fracture or sharp turns. The rod should terminate in a sharp point, which is generally a gilded copper cone. The conductor should be kept as far as possible from masses of metal in or near the building, for these would attract some of its electricity, which, in sparking from one to the other, might cause serious damage. Leaden roofs, water-runs, &c., which cannot be insulated from the conductor, should be directly connected with it, as in this case it completes their conducting connection with the earth, and the otherwise dangerous fluid will docilely follow the path prepared for it.

The base of the conductor should terminate in a well or stream of water. If this is not convenient, it may be connected with underground gas or water pipes, or embedded in charcoal filling a sewer at right angles to the building.

55. **Theory of Lightning Conductor.** Franklin thought that his kite and lightning conductor drew the electricity from the clouds. The reverse is true. A cloud charged with say + electricity, acts inductively on the part of the earth immediately beneath, attracting its −E, which streams off through the conductor to the cloud. This escape of the negative fluid not only prevents an accumulation of electricity on the earth's surface, but tends to neutralise the +E of the cloud. The opposite electricities are sometimes so abundantly generated that the conductor is unable to discharge the ground, and lightning flashes, but the conductor receives the charge and protects the building. In fact the conductor acts on the cloud just as the needle of Art. 51 acts on the machine. Lightning-rods are sometimes seen tipped with the electric light. (Art. 52.) This light, when seen on a ship's mast, is called by sailors *St. Elmo's fire.*

It follows from what has been said that the safest place during a thunderstorm is in the neighbourhood of non-conductors, and at a distance from sheets of water, trees, windows, bell-wires, chimneys, &c.

56. *Return Shock.* But even at a distance of several miles from a thunderstorm the effects of the electric discharge may be felt. A highly-excited cloud passing over Dublin, for instance, acts inductively on the surrounding country, say as far as Kingstown. When a discharge takes place at the metropolis the induction ceases, and bodies which had been excited at Kingstown rapidly return to the neutral state. This may be produced either by the escape of the induced fluid to the earth, or by a rush of its opposite to the body. *The effect* which is known as the *return shock* sometimes

proves fatal. Electrical disturbances of the air, even when too slight to leave visible traces, are perceived by persons of a nervous temperament. (Compare Art. 50, VI.)

CHAPTER IV.

VOLTAIC ELECTRICITY.

57. About the year 1780, Galvani, Professor of Anatomy in the University of Bologna, observed that a recently-skinned frog, suspended from a metal support near an electrical machine, exhibited convulsive movements every time a spark was taken from the prime conductor. These contractions he correctly attributed to the return shock (Art. 56). In 1786 he accidentally noticed similar contractions of the legs of a dead frog, suspended from a copper hook, as often as they came into contact with the iron railings to which the hook was attached. Succeeding experiments led Galvani to conclude that animals possessed an electricity peculiar to themselves, which he called the *vital fluid.* He published the result of his investigations in 1791, and in the succeeding year, Volta, Professor of Natural Philosophy in the University of Pavia, after repeating Galvani's experiments, denied the existence of animal electricity, and attributed the contractions to electricity generated by the contact of the metals. Volta was led to propound this "contact theory" from observing that the convulsions took place with greater energy when the frog's limbs were connected by different metals than when by only one.

Galvanism and *Voltaic Electricity* are but different names for this branch of the science, which is also called *current electricity.*

58. **Voltaic Pair or Couple.** When a plate of copper and a plate of *pure* zinc are wholly or partly immersed in water which has been rendered sour by the addition of a little sulphuric acid or common salt, nothing occurs so long as the metals do not touch each other; the arrangement has no effect on a magnetic needle, for instance. When the plates are connected, either by contact, or, what is more convenient, by uniting their exposed ends by a copper wire, a freely suspended magnetic needle held over the wire is deflected in a certain direction, and if the needle is held over the liquid, it is deflected in the opposite direction. If its N pole, for instance, was turned westward when over the wire, it will be turned eastward when over the liquid. On disconnecting the plates, the needle returns to the magnetic meridian.

From this it follows (1) that the junction of the plates gives rise to some power capable of deflecting the needle ; (2) that this deflecting power is possessed by both wire and liquid; and (3) that the direction in which it acts in the liquid is the opposite of that in which it acts in the wire. If we fancy the deflecting power to travel in a certain direction through the wire, it must, therefore, travel in the opposite direction through the liquid, just as a circular current possessing the disturbing influence would travel, starting say from the zinc and flowing through the liquid and wire back to the zinc again. Indeed these effects are said to be due to a *current* of electricity travelling as stated, and the path described by it is called a *circuit*, though the idea of a fluid flowing in a circuit is an image merely, and not a proved truth.

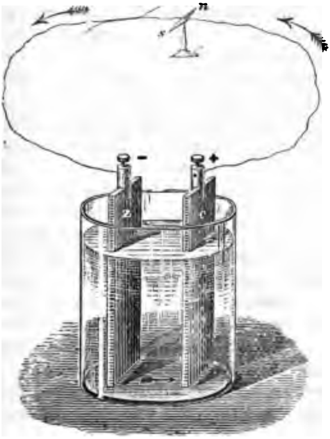

Fig. 21.—VOLTAIC PAIR.

59. After the apparatus has continued in action for some time, it will be found that the zinc has been partly dissolved by the acid, but the copper not. And had the connecting wire been of iron instead of copper, it would have been rendered red hot.

The action of the liquid on the zinc develops a force called *electromotive force*, which separates the two electric fluids, driving them in opposite directions, thus furnishing a continual supply of negative to the zinc and of positive to the liquid.

60. The mutual attraction of these fluids causes each to traverse the circuit in order to recombine with its opposite. The positive fluid is supposed to start at the surface of the zinc, and to flow through the liquid, copper plate, and connecting wire back to the zinc. The negative fluid follows the same path, but in the contrary direction. Now of course the opposing fluids flowing in opposite directions produce similar effects ; instead therefore of ascribing the deflection of the needle to a positive current flowing one way and a negative current flowing the opposite way, we ascribe the total effect to *the positive simply* as a matter of convenience, and for the

future, when we speak of *the current*, the positive current is meant. The existence of the negative current is tacitly ignored (Art. 63).

61. When the current is interrupted by cutting the wire, the – E is stopped in its course at the end connected with the zinc, which becomes in consequence negatively electrified, and for a like reason the end of the wire connected with the copper will be found positively electrified. The free ends of the plates, or of the wires connected with them, are called *poles* or *electrodes*. The zinc *pole* is thus negative, the copper *pole* positive, and as the immersed parts of the plates are in exactly opposite electrical states, the zinc is called the positive *plate* and the copper the negative. Speaking of the poles, the N in ziNc reminds us that it is the Negative pole, and the P in coPPer that it is the Positive.

When the plates are in conducting connection, that is, connected by a conducting wire such as copper, the current circulates, and the circuit is said to be *closed;* when the plates are not in conducting connection, the circuit is said to be *open* or *interrupted*.

The arrangement by which these effects are produced is called a *simple pair*, or sometimes a *Voltaic couple*. The metals and liquid may be different from those we have employed, but whatever the elements, the pair usually consists of *two dissimilar conducting plates immersed in a liquid which attacks one more vigorously than the other when the metals are connected by a conductor*.

62. The metals must be "dissimilar," for suppose both plates were of zinc, for instance, then the electromotive force generated by *each* would furnish a positive current to the liquid (Art. 60), and these currents flowing in opposite directions would neutralise each other. But it is not necessary that one plate should be wholly unaffected by the acid ; a current is started when "one is more vigorously attacked than the other." For the metal most attacked will produce the stronger current, and that less attacked the weaker, the effective current, or that which is actually perceived, being the excess of the strong over the weak. The metal most attacked is called the positive plate, that least attacked the negative.

63. Direction of current. The current always flows from positive to negative, that is, from the positive plate to the negative plate, and from the positive pole to the negative pole, and to ask what is the direction of a certain current is simply to inquire which is the positive and which the negative element of the couple (Art. 60).

Now as the acid acts very differently on different metals, a plate may be the positive element of one pair, and the negative of another. Thus of the three metals, zinc, copper, and silver, the acid attacks zinc more readily than copper, and copper more readily than silver. Hence copper is negative towards zinc, but positive towards silver. In the following list, called an *electromotive series*, the arrow indicates the direction of the current within the cell.

→

+ Potassium Sodium Magnesium Zinc Iron Aluminum Lead Tin Bismuth Copper Silver Mercury Platinum Gold Hydrogen Antimony Carbon Phosphorus Iodine Chlorine Nitrogen Sulphur Oxygen −

(Ferguson's *Elect.*, p. 122.)

It has been determined that the electromotive force between any two metals in the series is equal to the sum of the electromotive forces between all the intervening metals. (Art. 82.)

64. Protection of the negative plate. If we immerse plates of copper and zinc in nitric acid it attacks both metals, but the zinc more than the copper. On establishing a circuit, however, the zinc is more rapidly dissolved than before, while the copper is not at all acted on. And generally a metal may be wholly or partly protected from solution by placing it in conducting connection with a more electro-positive metal. Thus the copper sheathing of ships, which is dissolved by sea-water, may be shielded from this action by attaching strips of iron or zinc to it. Iron may be protected from rusting by a thin coating of zinc—it is then called *galvanised iron.* Zinc nails should be used for zinc roofs; iron nails form galvanic circuits with the zinc.

It may be here remarked that the ordinary zinc of commerce, not being pure (Art. 58), is rapidly dissolved by acidulated water, even when unconnected with the copper of the pair. It may be enabled to withstand this dissolution by cleansing it thoroughly in the acid, and then rubbing its surface with mercury till quite bright. "The zinc is dissolved by the mercury, detached from its impurities and presented to the liquid." The process is known as amalgamation, and the metal is then called amalgamated zinc.

65. Ampere's rule. We have already seen (Art. 58) that a current is capable of deflecting a magnetic needle placed above or below it. This important fact, indicating as it does a *definite relation between* electricity and magnetism, was discovered by Œrsted, a Danish philosopher, in 1819. A few months afterwards, Ampère announced the following rule for determining the direction of this deviation, viz.: *the north pole of the magnet is always deflected towards the left of the current.* That is, if the observer fancies himself embedded in the substance through which the current flows, so that it would pass through his body, entering by his feet and leaving by his head, when he faces the needle its north pole always turns toward his left hand.

The accompanying table exhibits the more common applications of the rule, which holds good whether the current passes horizontally (as here supposed), vertically, or obliquely.

Case.	Direction of Current.	Position of wire.*	Deflection of N. pole.
1	N. to S.	Above needle	East
2	N. to S.	Below "	West
3	S. to N.	Above "	West
4	S. to N.	Below "	East

* Or substance through which current passes.

66. Galvanometer. We learn from this table (by comparing cases 1 and 4, or 2 and 3) that opposite currents, one above and the other below the needle, tend to deflect it the same way. And further, when, instead of two wires, the current traverses one bent wire, all its parts (each of the sides of the rectangle, Fig. 22, for instance) tend to turn the needle in the same direction. For in all parts of the wire the observer's left hand points the same way. A little consideration will show that, were the figure described an ellipse or a circle, precisely similar results would be produced. (Fig. 23.)

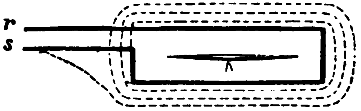

Fig. 22.

Of course if the wire passes twice round the needle the deflecting force is doubled, and generally by multiplying the number of convolutions of the wire, as represented by the dotted lines, we multiply to the same extent the force exerted on the needle, for each coil exerts its own deflecting force just as if it acted alone. Hence such an instrument has been called a *multiplier*, and as the amount of deflection of the needle is a rough measure of the strength of the current, it is also called a *galvanometer*. Sometimes both names are combined, *galvanometer multiplier*, or *multiplying galvanometer*.

The instrument may be conveniently used for detecting the existence or direction of a current by connecting the ends of the wire with little metal cups filled with mercury, the cups being placed in conducting connection with the poles of a galvanic circuit. On reversing the current, which can readily be done by dipping the battery wires simultaneously into the alternate cups, the needle is instantaneously deflected in the opposite direction. For a more expeditious method of reversing the current, see *Commutator*, Art. 74.

67. **Action of current on iron.** When a wire through which a strong current passes is immersed in iron filings, they adhere to it just as they would to a magnet, each filing setting itself at right angles to the direction of the current. On interrupting the circuit, the filings which had become induced magnets at once lose their power and drop.

68. If we place a bar of soft iron inside a glass tube and coil our wire round the tube (without overlapping), the current passing through the wire magnetises both coil and bar, with their similar poles pointing in the same direction. Ampère's rule (Art. 65) determines the disposition of the poles. From it we learn that when the wire is coiled in the form of a right-handed helix (that is, in the direction of the threads of an ordinary screw) the north pole is at the end where the current quits the coil. In a left-handed helix (one in which the wire takes the opposite direction) the north pole is at the end where the current enters.

69. *Electro-magnets.* If the wire is insulated by being "covered," that is, spun round with cotton or silk, we may coil it round and round the bar itself. *A rod or bundle of rods of wrought iron, round which an electric current circulates in a coil of wire, is called an electro-magnet.* The more numerous the convolutions the more highly is the rod magnetised, but it loses its power on interrupting the circuit. Permanent magnets may be made by thus passing currents round bars of well-tempered steel. Electro-magnets are generally of a horse-shoe shape, with the covered wire lapped round their ends only.

70. **Electric Telegraph.** The essential parts of an electric telegraph are—

(1) A *Voltaic battery* capable of generating the electric fluid.

(2) A *conductor* for transmitting this fluid; and

(3) An *indicator* for exhibiting the signals made by it.

The battery employed in the post office department of this country is a modification of Daniell's (Art. 80). The conductor, popularly known as the line, the wire, or the line-wire, consists of galvanised iron wire, supported on porcelain or glass insulators attached to buildings or to upright posts. Some indicators actually write the messages, others merely signal them.

71. When transmitting signals the line is connected with the + pole of a battery. Were the line-wire continued back to the – pole of the battery we would have an ordinary circuit, and in the first attempts at telegraphy such return and connexion was actually made. In 1838 Steinhill of Munich discovered that the return wire might be dispensed with by connecting the line wire with large metal plates sunk in the ground. (Compare Art. 54.) We are not to suppose that the current returns through the earth as it did through the "return wire," but that, owing to its immense size, the earth drains off the opposite electricities which would otherwise accumulate at the ends of the wire and stop the current. (See Art. 61.) And while the effect is the same whether the electricities are dissipated at the terminals or neutralise each other through the "return wire," the earth possesses the double advantage of costing nothing and of offering no resistance.

72. In COOKE AND WHEATSTONE'S SINGLE NEEDLE TELEGRAPH, Fig. 23, the instrument M for exhibiting the signals consists of a galvanometer placed vertically with the needle (not seen in fig.) inside. In front of the instrument, and attached to the same horizontal axis as the needle (so as exactly to indicate its movements), is the pointer W W. The lower end of the needle is loaded, so that when at rest the pointer is vertical. Certain deflections of the needle represent certain letters—in the old alphabet two deflections to the left (\\) indicate A, three B ; one to the right (/) M, two N, &c., &c.

73. The wire C is connected with the copper pole of the battery and Z with the zinc pole. E is the earth-wire (Art. 71), and L the line-wire. When the instrument is receiving signals the current from the line-wire enters at L, and (travelling in the opposite direction to that indicated by the arrows) after traversing the coil and deflecting the needle, passes up the metal spring S_1, down the corresponding spring S, and thence by the brass strip to E.

74. The *Commutator* or *Current Reverser* consists of a cylinder of wood, having its ends N P capped with brass or copper, and insulated from each other by the middle zone of the cylinder, which is left bare ; *c* and *z* are metal pins projecting from the brass cappings. When the instrument is in the receiving position, these, as we have just seen, stand vertical and are out of the circuit. N (or *z*) is permanently connected with the – pole of the battery by means of the spring *n* pressing against the axis A of the cylinder, while the spring *p*

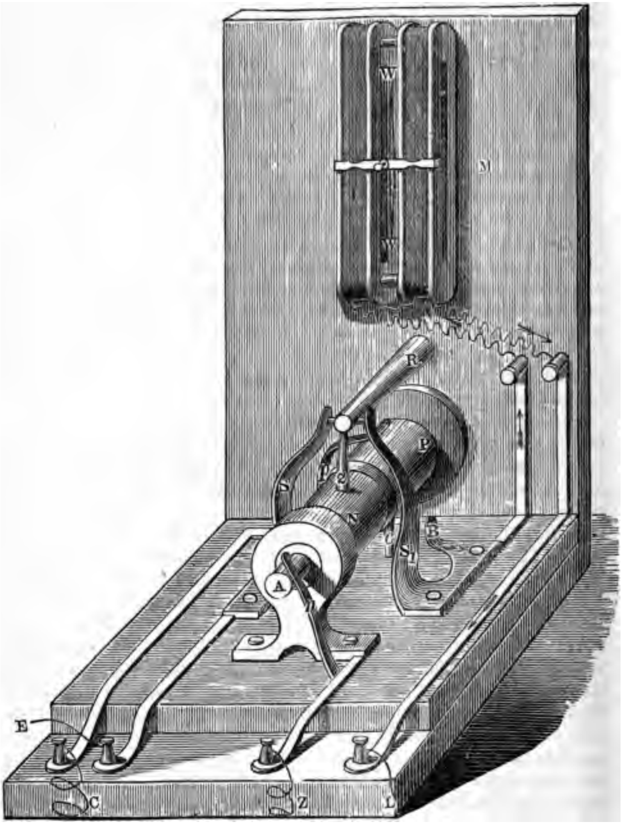

Fig. 23.—NEEDLE TELEGRAPH.

connects P (or *c*) with the + pole. From A the handle (not shown in fig.) which works the cylinder hangs vertically.

When the handle is moved to the right the pin *z* touches *the tall spring* S (pushing it away from the metallic rest R), and thus severing its connection with the corresponding spring S_1, while at the same time the pin *c* comes in contact with the metal boss B. The current from the positive pole of the battery then passes in succession the wire C, spring *p*, and brass strip to the brass capping P, down the pin *c*, and by means of the boss B, metal rod, and wire into the galvanometer, where, after deflecting the needle, it returns by the brass strip to the line-wire (as indicated by the arrows), then through the distant station and the earth (Art. 71), back to E, and thence by S_1 *z*, A, and *n* to Z, thus completing its circuit.

By turning the handle to the left we reverse the direction of the current through the coil, and of course the deflection of the needle. For in this case *z* makes contact with S_1, pressing it away from R, and at the same time *c* touches a metal boss (not shown) corresponding to B and on the other side of the fig. On putting the current to line it takes the course C, boss corresponding to B, then metal strip to E, earth, distant station, line-wire, L, coil, S_1, *z*, A, *n*, Z. On "turning the handle to the left" we are said to "put a zinc (reverse or negative) current to line," and if we consider this as *the* current (see Art. 63) its direction will be exactly the opposite of that just described.

It will be seen that turning the handle to the right connects the − pole with the earth, to the left the + pole.

The needle at the receiving station as well as that at the sending station is deflected to the side to which the handle at A is turned.

75. Chemical effects. *Decomposition of water.* In 1800 Carlisle and Nicholson discovered that water was capable of being decomposed into its constituent gases by passing through it a Voltaic current, generated by uniting several cells so as to form a battery. The process may be understood from Fig. 24, where V is a vessel containing acidulated water, into which project two strips of platinum which communicate by means of wires and binding screws with the poles of a battery. Over these platinum strips two glass tubes filled with water are inverted, and on completing the connections (as in the fig.) the passage of the current decomposes the water into two gases, which rise respectively from each strip into its surrounding tube. On examining the gases thus evolved, it is found that the strip by which the current enters the liquid (*i.e.*, the + pole) has given off oxygen, and the strip by which the current quits the liquid (the − pole) has set free hydrogen, and that the volume of hydrogen liberated is double that of the oxygen. If through a mixture composed of hydrogen and oxygen in the ratio of two volumes of the former to one of the latter we pass an electric spark, the gases unite to form water. We have thus a double proof of its composition, which is indicated by its chemical symbol H_2O.

When the tubes are graduated, so as accurately to measure the volumes of the gases evolved, the apparatus is called a voltameter.

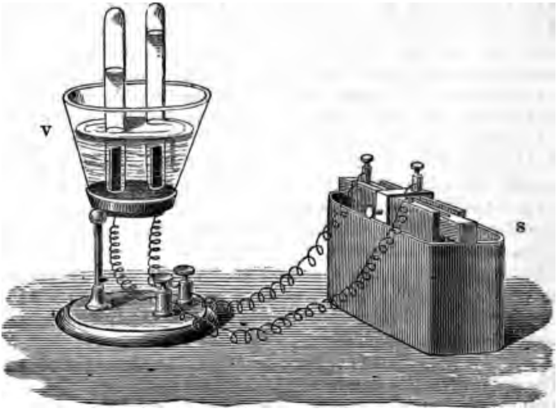

Fig. 24.
V. Voltameter. S. Cell of Smee's Battery.

In the foregoing experiment (as well as in Art. 58) the acid was added to the water to improve its conducting power, for pure water is a bad conductor of current electricity. The poles are made of platinum because this metal does not enter into chemical combination with either of the gases.

76. *Polarisation.* The case is different in the cell itself. There the liberated O attacks the zinc plate and combines with it, forming a dark solid, which remaining in the liquid thereby weakens its action on the zinc, while at the same time the copper plate becomes covered with a film of the liberated H, which being a bad conductor resists the passage of the current. Not only so, but the H being + with reference to the O (Art. 63), they start a current on their own account, which flows through the liquid from the + H (on the copper plate) to the − O (on the zinc plate), that is, in the opposite direction to the original current. In fact the H acts like a film of zinc (spread over the copper), and we know that *if both* plates were of zinc we would have no current (Art. 62), *or, what amounts* to the same thing, two equally strong

opposing currents. This *generation of a counter current, owing to the deposition of H on the negative plate, is known as the polarisation of that plate.*

77. "**Single fluid batteries** are subject therefore to three defects: their electromotive force is enfeebled by polarisation; it is not constant; and their resistance is not constant." For these reasons they are subject to a rapid decrease of power.

78. *Smee's* is perhaps the best of the single fluid batteries. In it each cell (see Fig. 24) consists of a thin sheet of silver or platinum hung in a wooden frame between two thick plates of amalgamated zinc (Art. 64); the whole being immersed in a vessel of dilute sulphuric acid. Polarisation is prevented by covering the negative plate (silver or platinum) with a deposit of finely divided platinum. This so roughens the surface as to diminish the adhesion of the hydrogen, which freely passes off from the minute points. This battery "gives a fairly constant current for many hours, is easily put in action, and no noxious fumes are evolved from it."

79. **Constant or two-fluid batteries** act with unabated energy for a considerable time. In them the polarisation of the passive plate is generally prevented by immersing it in a liquid which absorbs the liberated hydrogen.

80. The first and the most constant of these batteries was invented by *Daniell*, Professor of Natural Philosophy in King's College, London. Its construction and mode of action may be understood from Fig. 25, which represents a single cell. C is a copper cylinder, inside which is placed a cylindrical vessel (V) of porous unglazed earthenware, both cylinders open above. Inside the porous vessel is placed a cleft cylinder (Z) of amalgamated zinc. The porous vessel is filled with dilute sulphuric acid (one part of the acid to 8 or 10 of water), and the space between the copper and porous cylinders with a solution of sulphate of copper. This solution, popularly known as blue vitriol, is made by dissolving sulphate of copper (called also blue-stone ~~and copperas~~) in water. Crystals of the solid resting on a wire shelf attached to C keep the solution saturated.

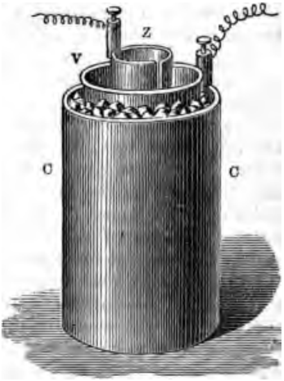

Fig. 25.—DANIELL'S CELL.

When the circuit is closed, by connecting the poles by a copper wire, the hydrogen generated at the surface of the zinc passes through the porous cell, but is intercepted by its surrounding liquid before reaching the copper plate. Several cells are united into a battery by connecting the zinc of one with the copper of another by means of copper wires.

81. **Grove's battery.** One of the forms of a cell of this battery is represented in section in Fig. 26, where G is a vessel of some non-conducting substance, say glass, containing dilute sulphuric acid, in which is immersed a cleft cylinder of zinc (Z), which serves as the positive plate. Inside this cylinder is the porous vessel V nearly filled with strong nitric acid, in which is placed a sheet of platinum (P) as negative plate. On completing the circuit the disengaged hydrogen passes through the porous vessel, but is prevented reaching the platinum plate by the intervening nitric acid, which it decomposes. Dense red fumes of a suffocating odour are given off.

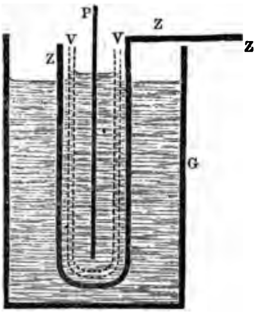

Fig. 26.—Grove's Cell.

82. *Bunsen's battery.* This battery only differs from Grove's in having carbon (instead of platinum) for the negative element.

The electromotive forces of a cell of Grove, Bunsen, and Daniell, are as 100 : 98 : 56. (See Art 63.)

83. *Callan's battery.* A cheap form of constant battery, sometimes called the cast-iron battery, was invented by Prof. Callan of Maynooth. In it a cylindrical vessel of cast-iron takes the place of the copper of Daniell's, and strong nitric acid is substituted for the sulphate of copper.

84. **Physiological effects.** In addition to those already enumerated, the following are noteworthy :—

(1) When the wires from a simple pair are made to touch the tongue a peculiar taste is perceived owing to the decomposition of the saliva, caused by the passage of the current; the current itself cannot be tasted.

(2) Place a silver coin on, and a piece of clean zinc below, the tongue. On bringing their edges into contact this saline taste is again perceived.

(3) When a snail or horse-leech is placed on a piece of silver resting on a zinc plate, on attempting to move off the

silver it receives a shock which instantly drives it back. Here, as in the preceding experiment, the juices of living bodies act as the conducting liquid.

(4) When the poles of a strong battery are held in the hands a violent shock is felt, especially if the hands have been moistened with acidulated water.

(5) Let the wire from one of the poles of a battery dip into water contained in a zinc can. Take the other pole in your left hand and try to lift a shilling from the bottom of the can. You will experience a shock on touching the water, and if the current is sufficiently strong you will be unable to *grasp* the shilling. (Compare Art. 41.)

85. **Luminous and heating effects.** If in experiment (2) of Art. 84 we place the silver under the tongue and the zinc between the upper lip and the gum, on bringing the metals into contact a flash of light is seen, owing to the action of the current on the optic nerve. A spark is obtained at the point of contact on closing a powerful circuit, and at the point of separation of the wires on interrupting the circuit.

A thick copper wire offers but little resistance to the passage of the current, and does not become heated. But if for the thick copper wire we substitute a thin wire of iron or platinum, it is soon raised to a white heat. A powerful battery is capable of melting all metals. The heating effects of the current are used in firing mines, blasting quarries, lighting gas-lamps of towns, &c., &c.

EXAMINATION QUESTIONS.

The numbers enclosed in brackets refer to the Arts. of text.

1. Tell me what you know about the loadstone or natural magnet. (1.)

2. You are to examine by means of a magnetic needle the magnetic condition of a piece of soft iron. You are also to examine the condition of a piece of magnetic iron ore of the same size and shape as the iron. State some of the differences which are sure to show themselves between both. (1, 4.)

3. How do magnetic poles act upon each other? What do you understand by a magnetic pole? (3, 2.)

4. How does the middle of a magnet act upon a piece of iron? How do the ends of the magnet act upon the same iron? Does any change occur in the iron when the magnet acts upon it? (2, 9.)

5. Sketch a bar magnet and letter its poles; show by dotted lines the manner in which iron filings arrange themselves round the bar magnet. (2.)

6. What do you understand by the polarity of a magnet? (2.)

7. Can you obtain a magnet with a single pole? Give the experimental grounds of your answer. (2, 8.)

8. You are required to demonstrate the law that like magnetic poles repel, and that unlike poles attract each other: how will you do it? (3, 5.)

9. A bar magnet, freely suspended horizontally, sets in the magnetic meridian. Supposing a second bar magnet to be suspended by the side of the first, how will they act upon each other? Make your answer clear by a diagram. (3, 5.)

10. I have two pieces of the same steel, of equal size, shape, and hardness; one piece is a magnet and the other not. State fully the particulars in which they differ from each other. (4.)

*11.** Give a clear sketch of the theory of magnetic fluids. (6.)

12. When iron is attracted by a magnet, the attraction represents the excess of one of two opposing forces; there is at the same time repulsion. Explain how this occurs. (7.)

13. A magnet is broken in two; describe the magnetic condition of its parts. (8.)

14. State the grounds of the belief that the smallest particles of a magnet are themselves perfect magnets. (8.)

15. How do you figure to yourself the change that occurs in a bar of unmagnetised steel when the pole of a magnet is rubbed along it? (9, 12.)

16. Near a ball of perfectly annealed soft iron the north end of a strong steel magnet is placed. What is the action of the magnet upon the ball? What change occurs in the ball when the magnet is withdrawn? and what occurs when the south pole of the magnet instead of the north is placed near the ball? Illustrate your answer by diagrams. (9.)

*17.** In the previous question is there anything calling for qualification in the expression "the action of the magnet upon the ball"? (9.)

18. The pole of a magnet is drawn over an unmagnetised bar of steel; state in the language of the theory of magnetic fluids what occurs. (9, 12.)

19. State what you know regarding the difference between iron and steel, as regards the acceptance and retention of magnetism. (11.)

*20.** Give an account of magnetic induction and of coercive force in the language of the theory of magnetic fluids. (9, 11.)

21. A steel sewing needle is drawn over the north pole of a magnet from eye to point; what is the subsequent condition of the needle? The point is presented to the north end of a mariner's compass needle; what occurs? (12, 3.)

22. Supposing you break the sewing needle referred to in the last question in two, and present the two ends of each half in succession to the north end of a mariner's compass needle; what occurs? (8, 3.)

23. You are provided with a steel sewing needle, and are required to magnetise it so as to render its *point* a south pole; how will you do it? (12.)

24. What do you think causes a magnetic needle to set north and south? Does its direction ever vary? if so, state what you know regarding the variation. (13.)

25. Supposing the top of the page on which you are writing to represent the north and the bottom the south, you are required to draw the true geographical meridian. Then to draw a magnetic needle in the position which it occupies with reference to that meridian, and to mark on your figure the angle of declination and the number of degrees it embraces in our latitude. Why do I use the words "our latitude"? (14.)

26. What is meant by the declination and inclination of the magnetic needle? What is meant by the terms magnetic dip, magnetic poles, and magnetic equator? (14, 15, 16.)

27. State what you know regarding the use of the magnetic needle in the steering of ships. (14.)

28. Describe the dipping-needle. What is the magnetic condition of an iron bar when placed in the direction of the dipping needle? What do you suppose throws the iron bar into this condition? What occurs when you reverse the position of the bar? (15, 18.)

29. You carry with you a dipping-needle from the earth's north magnetic pole across the equator to the south magnetic pole; how will the dipping-needle behave during this excursion? (16.)

30. People sometimes say that "the earth is a magnet." What do they mean? (18.)

31. A long strip of hard steel is magnetised, and when a small magnetic needle is passed along it, its north point is attracted by one end of the strip, its south point by the other, the centre of the strip appearing to attract neither point of the needle. When the strip is broken across at the centre, what is the action of the two halves upon the magnetic needle? (18, *par.* 2; 8.)

*32.** How am I to hold an iron bar so that it shall receive its maximum of magnetisation from the earth? How, when held in this position, is such a bar to be tested? (18, *par.* 3.)

33. You possess a small magnetic needle with the end which points to the north marked N., and that which points to the south marked S. An iron poker which has been perfectly annealed is placed upright, and the magnetic needle is brought first near the bottom of the poker, and then gradually raised, past the centre to the top. The poker acts upon the needle, and you are required to describe its action. (18, *par.* 3.)

34. The marked end of a magnet is attracted by the earth's north magnetic pole; but if the magnet be set floating on a cork it does not move towards the pole. Why? (19.)

35. From what is the word *electricity* derived? Describe the substance with which the first electrical effects were observed, and describe also the mode of exciting it. (20.)

36. I wish you to show me a few electrical effects; how will you do it? (21, 24, 25.)

37. If upon a warm board a dry sheet of paper be rubbed with india-rubber it is electrified. How is this proved? (21.)

38. A sheet of hot paper is placed on a hot board, and india rubber is passed briskly over it. Two strips are cut from the paper and held up close and parallel to each other. How will they act upon each other? A glass rod rubbed with silk repels both strips; what is the inference? (21, 27.)

39. You are required to electrify strongly a glass tube; how will you do it? You are required to electrify strongly a tube of gutta-percha; how will you do it? (22.)

40 If you take an insulator in your hand and rub it properly, you electrify it; if you do the same with a conductor, you obtain no signs of electricity; what is the reason? Bodies were formerly divided into electrics and non-electrics; why? (22.)

41. Two strings are given to you, and you are required to test whether they insulate or conduct electricity; how will you do it? (22.)

42. What is meant by the term insulated? I bring a glass rod which has been rubbed with silk near an insulated brass sphere; what is the condition of the sphere while the glass is near it? What occurs when the glass is removed? (22, 29.)

43. An apple held in the hand and struck with a fox's brush shows no sign of electrical attraction; suspended by a string of silk and struck with the brush it becomes electrified, attracting light bodies and causing the leaves of the electroscope to diverge. Explain these results. (22.)

44. Give a concise sketch of the theory of electric fluids. (28.)

45. I wish you to prove that like electricities repel each other, and that unlike electricities attract each other; but you *are first* to state what image you have in your mind when you *speak of electricity* at all. (24, 25, 28.)

46. Show by a simple experiment that the electricity developed on resin by the friction of flannel is different from that developed on glass by the friction of silk. (24.)

47. What is the action of two electrified glass tubes upon each other? What is the action of two electrified gutta-percha tubes upon each other? What is the action of an electrified glass tube upon an electrified tube of gutta-percha. (25.)

48. Du Fay announced the discovery of two kinds of electricity, which he called vitreous and resinous. State your grounds for holding the classification to be incorrect. (26.)

49. There are two kinds of electricity, called *positive* and *negative*. You rub sealing-wax with flannel; are both electricities excited, or are they not? If both, where? If only one, where? (27.)

50. We often hear of an "electric fluid." What are your notions regarding it? (28.)

51. Do you know what electrical induction is? If so, describe an experiment which shall illustrate it. (29.)

52. I hold a dry glass rod which has been rubbed with silk near a brass ball which is supported on a dry glass stand; what is the state of the ball? Supposing the stand which holds the brass ball to be moist instead of dry; what will occur? (29, 22.)

53.* Two insulated metal spheres are united by a chain; a body positively electrified is placed near one of them; what is the condition of the other? You touch the sphere adjacent to the electrified body; what occurs? Finally, you remove the electrified body; what occurs? (29.)

54. A stout stick of sealing-wax is stuck upright to a piece of wood acting as a base; into the wax at the top is inserted a needle, and on to the needle is fixed an apple. Near to the apple, but not into contact with it, is brought a rod of glass which has been rubbed by silk. What is the condition of the apple while the rod remains near it? What occurs when the apple is touched for a moment? What finally occurs when the rubbed glass is withdrawn? (29.)

55. An apple rests on a stick of sealing-wax as a support. The point of a needle stuck in the apple protrudes from it, and in front of the needle a piece of gutta-percha which has been rubbed by flannel is for a moment held. On removing the gutta-percha, the apple is found charged with electricity. How has it become so, and with what electricity is it charged? (29, 51.)

56. In the foregoing experiment the point of the needle was turned towards the excited gutta-percha. Supposing it to be turned away from it, the gutta-percha being brought for a

moment near the opposite face of the apple, what will be the condition of the apple when the gutta-percha is withdrawn? Give your reasons for your answer? (29, 51.)

57. State fully the particulars wherein magnetic induction and electric induction agree; also the particulars wherein they differ. (9, 30.)

58. Explain, in accordance with the theory of electric fluids, the attraction of light bodies by an electrified glass rod. (31.)

59. An electrified body is brought near a scrap of paper or of gold-leaf resting on a metallic surface, what happens to the scrap, and what is its exact electrical condition when it is attracted? Supposing it to rest on a surface of shellac, what would be its condition when attracted? (31.)

60. Why is repulsion a surer test of the electric condition of a body than attraction? (32.)

61. Describe the gold-leaf electroscope, and state the principle of its action. (34.)

62. I grind sulphur in a mortar and thus electrify it. I place some of the electrified powder on the plate of a gold-leaf electroscope; the leaves diverge; why? since sulphur is an insulator and does not part with its electricity. I remove the powder by means of an insulator; what will occur, and why will it occur? (29, 34.)

63. Describe the electrophorus and the mode of charging it. (38.)

64. I stick a bit of sealing-wax against a penny or a half-crown; and I whisk a bit of vulcanised india-rubber with a fox's brush. Holding the sealing-wax as a handle, I lay the penny or half-crown flat on the india-rubber. What is the condition of the coin? I touch the coin, what occurs? I lift it by the handle, what is its condition? (38.)

*65.** Describe the condenser, and illustrate its use. (39.)

66. Describe Franklin's plate, and explain its action. (40.)

67. I place a sheet of vulcanised india-rubber on a sheet of tinfoil, and a second sheet of tinfoil on the rubber. I connect the lower sheet with the earth, and the upper one with the conductor of an electrical machine; what occurs when the machine is set in action? (39, 40.)

68. Describe and explain the original experiment which led to the discovery of the Leyden jar. (42.)

69. A Leyden jar is hung up in the air by a silk string; the knob of the jar is connected with an electric machine, and its outer coating is connected by a wire with a large gas-pipe. What occurs in this outer wire when the machine is worked, and why does it occur? (43.)

70. Why do I employ a silk string to suspend the jar in the last experiment? What would happen supposing the string to be ordinary twine? (43, 22.)

71. You are required to charge and discharge a Leyden jar; how will you do it? (43.)

*72.** You are required to charge a series of Leyden jars by means of the charge communicated to a single jar; how will you do it? (46, 47.)

73. Describe some form of the electric machine, and explain its use. (48.)

*74.** Explain fully the action of electrified points, and apply your knowledge to the case of lightning conductors. (51, 54.)

*75.** Describe and explain Franklin's experiment with the kite, by which he demonstrated the existence of atmospheric electricity. (53.)

76. How do you suppose thunder and lightning to be produced? (53.)

77. What are lightning conductors? and how do they act in averting danger from lightning? (54, 55.)

*78.** Describe and explain the return shock. (56.)

79. Show the possibility of a man being killed by atmospheric electricity at the distance say of a mile from the point where the discharge occurs. (56.)

80. Who was Volta? Who was Galvani? Why do we hear sometimes of voltaic electricity and sometimes of galvanic electricity or galvanism? Is there any difference between voltaic and galvanic electricity? (57.)

81. What do you understand by an electric current? (58.)

82. If you wanted to prove that an electric current acts upon a magnetic needle, give me a clear statement of how you would proceed. (58, 65.)

83. What do you understand by a voltaic circuit? (58.)

84. I wish you to produce an electric current; how will you do it? Can you see, feel, or taste this current? If not, what proof have you of its existence? (58, 84, 85.)

85. What is meant by the direction of the current? (58, 63.)

86. A steel knife and a silver fork are plunged into the same orange; what occurs when the metallic portions of both are united? (58.)

87. You have a strong cell containing a plate of platinum and a plate of zinc, and as a liquid dilute sulphuric acid. What occurs in the liquid when the two metals are united? Does anything occur that you can actually see? (76, 59.)

88. If the same electric current be sent through a silver wire and an iron wire of the same thickness, the iron wire will become hotter than the silver. Why? (59, 85.)

89. If a strong voltaic current is sent in succession through a thin platinum wire, through acidulated water, and then through a wire which surrounds a common poker, what is the effect produced in each case? (59, 75, 67, 85.)

90. A steel fork and a steel knife are connected by wires with a galvanometer. The knife and fork are used to cut a juicy and well-salted beefsteak, what will be the effect upon the galvanometer? What will be the effect when a silver fork is substituted for the steel one, the steel knife being retained? (62, 66.)

91. How are the wires carrying a voltaic current usually insulated? What is the meaning of insulation? (69, 70, 22.)

92. In what particulars does an electro-magnet differ from an ordinary steel magnet? (69.)

93. Amalgamated zinc plates are employed in Grove's voltaic battery. How are the plates amalgamated, and what useful purpose does the amalgamation serve? (64.)

*94.** State concisely the influence of the direction of a current upon the deflection of a magnetic needle on which the current acts. Can you infer the deflection from the direction and the direction from the deflection? (58, 65.)

95. A current flows through a telegraph wire between Edinburgh and London, but we do not know whether it comes from Edinburgh or London. Supposing this knowledge desired, how would you obtain it? (65.)

96. Describe and explain the ordinary multiplying galvanometer. (66.)

97. How would you illustrate by an experiment the magnetic condition of a wire through which an electric current flows? (67, 68.)

98. You wish to convert a poker into an electro-magnet with its knob as a north pole. Show by a sketch how it is to be done. (68.)

99. Describe and illustrate by a sketch how water may be decomposed by an electric current. Two gases are formed; what are they, and where do they make their appearance? (57.)

*100.** What is the meaning of the term "polarisation" as applied to the plates of platinum immersed in the voltameter? how is it produced? (76.)

*101.** Describe the battery of Daniell. (80.)

102. Give a sketch of a cell of Grove's battery, and state the uses of the various parts. (81.)

103. I place a bit of silver on my tongue, and a bit of zinc under it, and cause the two pieces of metal to touch each other; what occurs? Describe some means of proving that an electric current is generated? (84.)

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